Atacama
Large
Millimeter
Array

ANNEX 5

Technical Specification

for the

Design, Manufacturing, Transport and Integration on Site

of the

64 ALMA ANTENNAS

ALMA-34.00.00.00-006-A-SPE

Version: A

Status: *Released*

2003-12-15

Prepared By:		
Name(s) and Signature(s)	**Organization**	**Date**
V. Gasho — Signature Not Verified — Victor L. Gasho	NRAO	
S. Stanghellini — Stefano Stanghellini 2003.12.16 17:30:10 + 01'00'	ESO	
Approved By:		
Name and Signature	**Organization**	**Date**
D. Sramek — R. Sramek — Richard Sramek 2003.12.17 08:26:32 -07'00'	NRAO	
C. Haupt — Signature Not Verified — Christoph Haupt 2003.12.16 18:41:52 + 01'00'	ESO	
M. Rafal — Signature Not Verified — Marc D. Rafal — Digitally signed by Marc D. Rafal Date: 2003.12.16 13:47:29 -05'00'	NRAO	
R. Kurz — Richard Kurz — Richard Kurz 2003.12.16 21:46:33 +01'00'	ESO	
Released By:		
Name and Signature	**Organization**	**Date**
M. Tarenghi — A. Arndt for M. Tarenghi 2003.12.17 08:40:04 + 01'00'	JAO	

Change Record

Version	Date	Affected Section(s)	Change Request #	Reason/Initiation/Remarks
A	2003-12-15	All	n.a.	First issue

1 SCOPE

This specification establishes the performance, design, development and test requirements, which apply to the ALMA 12-m antennas.

The specification covers furthermore the manufacturing, assembly on site, integration, alignment, testing of the antennas. This also includes integration, service and testing equipment, which is necessary for the alignment, the maintenance and testing of the antenna.

The Statement of Work that encompasses this specification is the "Statement of Work for Design, Manufacture, Transport and Integration on Site of the ALMA Antennas".

2 ACRONYMS AND DEFINITIONS

2.1 ACRONYMS

ABM	Antenna Bus Master
ACU	Antenna Control Unit
ALMA	Atacama Large Millimeter Array
AOS	Array Operation Site
AUI	Associated Universities Incorporated
BUS	Back-up Structure
CFRP	Carbon Fiber Reinforced Plastic
CPU	Central Processing Unit
CRT	Cathode Ray Tube
DC	Direct Current
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
ESO	European Southern Observatory
FEA	Finite Element Analysis
GHz	Gigahertz
HVAC	Heating Ventilation and Air Conditioning
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LRU	Line Replaceable Unit
LEMP	Lightning Electro-Magnetic Pulse
LPZ	Lightning Protection Zone
MHz	Megahertz
MLE	Maximum Likely Earthquake
MSDS	Material Safety Data Sheets
MTBF	Mean Time Between Failure
NEC	National Electric Code
NEMA	National Electric Manufacturer Association
NRAO	National Radio Astronomy Observatory
NSF	National Science Foundation
OEM	Original Equipment Manufactures
OSF	Operations Support facility
PCU	Portable Control Unit
RBW	Resolution Bandwidth
RF	Radio Frequency

RFI	Radio Frequency Interference
RMS	Root-Mean-Squared
RSS	Root Sum of the Squares
RTAI	Real Time Application Interface
SPD	Surge Protective Device
TÜV	Tecnische Überwachung Verein
UL	Underwriters Laboratories
UPS	Uninterruptible Power Supply
VA	Volt-Ampere
VAC	Volt Alternating Current

2.1.1 DEFINITIONS

For the interpretation of the present specification the following definitions apply:

<u>ALMA</u>
For the purpose of this Technical Specification the term ALMA means the entity monitoring the execution of the Contract as set forth in the Statement of Work.

<u>Differential Accuracy</u>

In the positioning of the subreflector this is the error of the system in producing the desired positioning step from the previous position

<u>Settling time</u>

The time required following the signal initiation of the positioning step or correction to reposition and maintain the system within the narrow band constituted by the absolute or differential accuracy.

<u>Site</u>
The work area assigned to the Contractor at the Operations Support Facility (OSF) in Chile for the activities linked to the assembly and testing of the antennas.

3 APPLICABLE DOCUMENTS

The following documents are applicable to this Technical Specification to the extent specified herein. In the event of conflict between the documents referenced herein and the content of this Technical Specification, the content of the Technical Specification shall be considered as a superseding requirement.

3.1 GENERAL DOCUMENTS

AD [1] ALMA Coordinate Systems Specifications,
ALMA-80.05.00.00-009-B-SPE

AD [2] ALMA Environmental Specification,
ALMA-80.05.02.00-001-B-SPE

AD [3] ALMA Power Quality (Compatibility Levels) Specification,
ALMA-80.05.00.00-001-C-SPE

AD [4] ALMA Standard for AC Plug, Sockets-outlets, and Couplers,
ALMA-80-05-00-00-004-B-STD.

AD [5] ALMA System Electromagnetic Compatibility (EMC) Requirements,
ALMA-80.05.01.00-001-A-SPE

AD [6] ALMA System Electrical Design Requirements[1],
ALMA-80.05.00.00-005-B-SPE

AD [7] ALMA System General Safety Design Specification,
ALMA-10.08.00.00-003-B-SPE

AD [8] ALMA Documentation Standards
ALMA 80.02.00.00-003-F--STD

3.2 INTERFACE CONTROL DOCUMENTS

This section lists the documents governing the interfaces of the antenna.

ICD [01] Antenna Stations and Antenna,
ALMA-20.02.00.00-34.00.00.00-E-ICD

ICD [02] Antenna and ALMA Power Distribution System,
ALMA-20.05.00.00-34.00.00.00-B-ICD

ICD [03] ALMA Antenna and ALMA Antenna Transporter
ANTD 34.00.00.00-37.00.00.00-A-ICD

---

1 The applicable document AD03 of AD [6] is not applicable to this Technical Specification.

ICD [04] Interface Control Document between Antenna and Front End.
ALMA-34.00.00.00-40.00.00.00-A-ICD

ICD [05] ALMA Antenna and Back End,
ALMA-34.00.00.00-50.00.00.00-B-ICD

ICD [06] Antenna and ALMA Computing & Control Software,
ALMA-34.00.00.00-70.35.20.00-B-ICD

ICD [07] ALMA Antenna and Holography Receiver
ALMA-34.00.00.00-42.02.00.00-A-ICD

3.3 DRAWINGS

DWG [01] Transport Design Volume
ANTD-34-00.00.00.-002-A-DWG

DWG [02] Clearance profile for passage in the Central Cluster
ANTD-34-00.00.00.-005-A-DWG

DWG [03] Receiver Installation Platform
ANTD-34-00.00.00.-010-A-DWG

DWG [04] Subreflector Central Cone
ANTD-34-00.00.00.-008-A-DWG

DWG [05] Optical Telescope Flange and Volume
ANTD-34-00.00.00.-009-A-DWG

DWG [06] Apex Flange and Volume
ANTD-34-00.00.00.-003-A-DWG

DWG [07] On-Axis Cable Wrap
ANTD-34-00.00.00.-004-A-DWG

DWG [08] Receiver Cabin General layout: Reserved for later

3.4 STANDARDS

The following documents of the exact issue shown form a part of this specification to the extent specified herein. Where no issue or date is indicated, the latest editions/revisions thereof and any amendments or supplements thereto in effect on the date of the Contract Documents shall be taken as valid. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement.

Note: In lieu of DIN or ISO standards the Contractor may be authorized to use equivalent national standards (after prior written approval by the ALMA Technical representative).

AD [9] IEC 60204-1
Safety of machinery - Electrical equipment of machines – Part 1: General requirements
or
NFPA 79, Electrical Standard for Industrial Machinery

AD [10] American Institute of Steel Construction - Manual of Steel Construction
or
Structural steelwork DIN Norms 18800-1, 1/A1, 2, 2/A, 3, 4, and 5.

AD [11] IEC 60364
Electrical installations of buildings
(all the 'Parts' of the standard insofar as applicable)

AD [12] Occupational Safety and Health Administration - OSHA
Regulations (Standards - 29 CFR)
PART 1910 Occupational Safety and Health Standards
PART 1926 Safety and Health Regulations for Construction

AD [13] VDE 1000 - DIN 31000, 1979-03,
General principles for the safe design of technical products.

AD [14] IEC 60664
Insulation coordination for equipment within low-voltage systems
(all the 'Parts' of the standard insofar as applicable)

AD [15] IEC 61140
Protection against electric shock - Common aspects for installation and equipment

AD [16] ISO 4413
Hydraulic fluid power -- General rules relating to systems.

AD [17] UL 60950-1 or IEC 60950-1
Information technology equipment - Safety - Part 1: General requirements

AD [18] European Convention for Constructional Steelwork – ECCS
Code no. 52, 1987
Recommendations for calculating the effect of wind on constructions

AD [19] Eurocode No 8: Design of structures for earthquake resistance, Part 1, CEN, European Committee for Standardization, prEN 1998-1, Draft No. 6, January 2003

AD [20] ANSI Z136.1
Safe Use of Lasers
or
IEC 60825
Safety of laser products
(all the 'Parts' of the standard insofar as applicable)

AD [21] IEC 61024
Protection of structures against lightning

in particular:
IEC 61024-1, General principles.
IEC 61024-1-2, General principles – Guide B – Design, installation, maintenance and inspection of lightning protection systems.

AD [22] IEC 61312
Protection against lightning electromagnetic impulse (LEMP)
in particular:
IEC 61312-1, General principles
IEC/TS 61312-2, Shielding of structures, bonding inside structures and earthing
IEC/TS 61312-3, Requirements of surge protective devices (SPDs)

AD [23] DIN 15018-1
Cranes; steel structures; verification and analyses

AD [24] DIN 15018-2
Cranes; steel structures; principles of design and construction.

AD [25] DIN 15018-3
Cranes; principles relating to steel structures; design of cranes on vehicles.

AD [26] IEC 61000
Electromagnetic Compatibility
(all the 'Parts' of the standard insofar as applicable)

AD [27] VG 95374
"Electromagnetic Compatibility (EMC) including Electromagnetic Pulse (EMP) and Lightning Protection - Programme and Procedures "
published (also in English) by the German "*Bundesamt für Wehrtechnik und Beschaffung*".

(Note. Similar reference standard/s may be followed by the Contractor, provided it/they be previously submitted to ALMA for approval.)

4 ANTENNA FUNCTIONAL AND PERFORMANCE REQUIREMENTS

4.1 ANTENNA GENERAL DESCRIPTION

The Atacama Large Millimeter Array (ALMA) is an equal partnership between Europe and North America, in cooperation with the Republic of Chile to build an astronomical observatory that will operate at millimeter and sub-millimeter wavelengths (0.3 to 10 millimeters, corresponding to a frequency range extending from 30 GHz to 950 GHz). The observatory will be a synthesis radio telescope constituted by 64 antennas each of 12 m diameter, operating in interferometric mode.

Astronomical observation will be carried out at the Array Operation Site (AOS) located at an elevation of 5000 meters above sea level on the Chajnantor plateau in the Atacama desert in northern Chile. The antennas will be relocated at various intervals by means of a dedicated antenna transporter between a large number[2] of antenna stations spread over an area of approximately 20 km extension. The antennas will be bolted to the reinforced concrete foundations buried in the ground. An assembly and maintenance facility, the Operation Support Facility (OSF) will be constructed near San Pedro de Atacama to support the observatory during the construction and operation phase.

The antennas will operate in free air during daytime and night time, as long as the atmospheric condition will remain inside the specified operating limit. When not in an operating condition the antenna will be put in a safe “stow” configuration.

The antennas will be constituted by a symmetrical paraboloidal reflector, of 12 m diameter, with a Cassegrain optical layout mounted on an Altitude-Azimuth mount.

The primary reflector surface will consist of machined aluminum panels or electro-deposited nickel panels. The reflector surface will have a suitable surface finish to enable direct solar observing. The reflector surface will be mounted by means of adjusters onto a reflector backup structure (BUS). The BUS will be constructed of carbon fiber reinforced plastic (CFRP) in order to guarantee the thermal stability demanded by the antenna.

The subreflector with its mechanism will be supported by feed legs in a quadripod configuration. The position of the subreflector will be remotely adjusted with a controlled mechanism for focusing and collimation. For specific observations a nutator will be mounted onto the subreflector mechanism. The nutator is not part of this specification.

The antenna will be equipped with a receiver cabin mounted on the elevation structure where the receiver instrument and electronic equipment will be mounted for astronomical observation. An access platform will be provided in front of the receiver cabin door for personnel access and instrument installation.

[2] It is expected that more than 200 antenna stations will be constructed.

4.2 INTERFACE REQUIREMENTS

This section provides information about the interfaces of the antenna and lists the applicable documents or the sections of the present specifications where the various interface requirements are specified.

4.2.1 INTERFACE WITH THE ANTENNA STATIONS

The term "Antenna Station" refers to all stations where an antenna can be mounted, irrespective of its location. Antenna stations will be available at the OSF site for assembly and testing purposes.

The details of the interface between the antenna and the Antenna Station are defined in the ICD [01]. The ICD defines the geometry of the attachment and the mechanical characteristics of the foundation. Furthermore, it defines the position and geometry of the vaults for the electric power and for the signals routed to the antenna through the station.

4.2.2 INTERFACE WITH THE ALMA POWER DISTRIBUTION SYSTEM

The details of the interface between the antenna and the ALMA Sites power distribution systems are defined in the ICD [02]. Electric power is provided to the antenna through a vault in the antenna station.

4.2.3 INTERFACE WITH THE ANTENNA TRANSPORTER

The details of the interface between the antenna and the transporter are defined in the ICD [03]. The ICD defines also the procedures for removal and installation of the antenna.

4.2.4 INTERFACE WITH THE FRONT END

The details of the interface between the antenna and the Front End are defined in the ICD [04]. The ICD defines the masses and the volumes of the receiver instrument and the associated calibration devices. The requirements in terms of mechanical positioning and stability as well as the thermal requirements are included.

4.2.5 INTERFACE WITH THE BACK END

The details of the interface between the antenna and the Back End are defined in the ICD [05]. The ICD defines all requirements pertaining to the mounting of the various electronic assemblies constituting the Back End

4.2.6 INTERFACE WITH THE ALMA COMPUTING AND CONTROL SOFTWARE

The details of the interface between the antenna and the ALMA Computing and Control software system are defined in ICD [06]. The communication cables to the antenna are physically routed through the signal vault in the antenna station, defined in ICD [01].

4.2.7 INTERFACE WITH THE EXTERNAL (ALMA) CABLES AND PIPING

The details of the interface between the antenna and the ALMA supplied cables and piping which will be routed in the antenna are included in Section 6.9.2, of this specification, which provides the listing of the cables and pipes. Because they are resulting from the integration of the various ALMA systems (Front End, Back End, Holography receiver, and Optical pointing telescope, computing…), individual listing of cables and pipes and specific requirements are to be found also in the relevant ICDs.

The interface with the on-axis cables is defined in applicable DWG [07].

4.2.8 INTERFACE WITH FRONT END SERVICE VEHICLE

The details of the interface between the antenna and the Front End Service Vehicle are defined in Section 7.1 of this specification.

4.2.9 INTERFACE WITH THE OPTICAL POINTING TELESCOPE

The details of the interface between the antenna and Optical Pointing Telescope, which will be used for acceptance testing, are defined in Section 7.4.3 of this specification, and in the applicable document DWG [05].

4.2.10 INTERFACE WITH THE HOLOGRAPHY RECEIVER

The details of the interface between the antenna and Holography Receiver are defined in applicable document ICD [07].

4.3 ANTENNA PHYSICAL CHARACTERISTICS

4.3.1 SYSTEM OF COORDINATES

All Systems of Coordinates used for the Antenna shall comply with the requirements of applicable document AD [1].

4.3.1.1 Antenna Pad Coordinate System

The antenna Pad Coordinate System (or Foundation Coordinate system) is defined in applicable document ICD01. Its characteristics are mentioned here for ease of use. This system of coordinates is indicated by O_p, X_p, Y_p, $Z_{p.}$

The Pad Coordinate system is a Cartesian system, based on the right-hand rule, with the Z_p corresponding to the local vertical, positive direction toward zenith, and Y_p axis pointing to the geographical North. The origin of the system is in the plane of the embedded flanges at the antenna pad, at the nominal center of the as-built pad, as defined by the kinematic mount of the antenna.

4.3.1.2 Reflector Coordinate System

The reflector coordinate system is defined by Figure 4.3.1.a.

It is a Cartesian coordinate system, based on the right hand rule, fixed to the yoke of the antenna. This system of coordinates is indicated by O_R, X_R, Y_R ,$Z_{R.}$ The nominal position of the origin is the intersection between the elevation and the Azimuth axes. The X_R axis is constituted by the elevation axis of the antenna, The Z_R axis is the nominal boresight of the antenna, positive toward the subreflector, and the Y_R axis according to the right hand rule, positive in the direction opposite to the receiver cabin door. As such when the azimuth of the antenna is equal to zero, the X_R axis is parallel to the X_p axis.

4.3.1.3 Focal Plane Coordinate system:

The Focal plane coordinate system is defined in Figure 4.3.1-a.

It is a system which is centered on the secondary focus of the antenna, and parallel to the Reflector coordinate system. This system of coordinates is indicated by O_F, X_F,, Y_F , Z_F

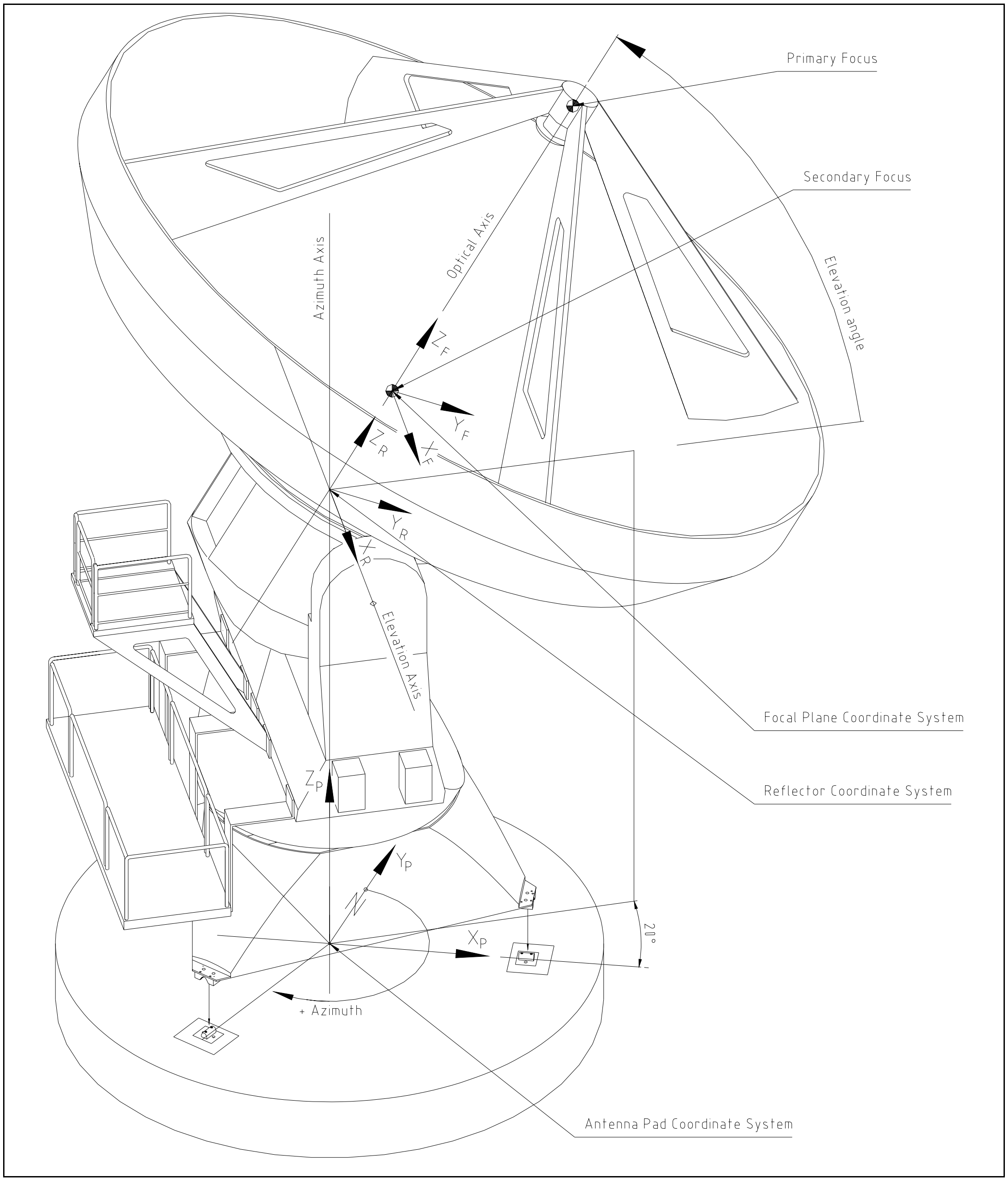


Figure 4.3.1-a: System of Coordinates

4.3.1.4 Azimuth of the antenna

The Azimuth angle shall be zero when the antenna is rotated so that Y_R is pointed toward North and X_R is pointing toward East. The Azimuth angle origin is then counted from the positive Y_P (North), positive direction when the antenna moves in the clockwise direction

(Azimuth angle = 90 when X_R is pointing toward South).

4.3.1.5 Elevation of the antenna

The Elevation shall be set to zero when the Z_R axis is pointing to horizon and to +90 when the Z_R axis is pointing toward Zenith (Antenna pointing to Zenith).

4.3.2 OPTICAL CONFIGURATION

The antenna shall be a symmetrical paraboloid reflector of 12 m diameter with a Cassegrain geometry. The subreflector support legs shall have a quadripod configuration.

The Antenna optical configuration parameters are given in Table 4.3.2-1

D	Primary Aperture	12.0 m
f_p	Focal Length of Primary	4.80 m
	f_p / D of Primary	0.40
D	Secondary Aperture	0.75 m
	Final f / D	8.00
	Magnification Factor	20.0
θ_p	Primary Angle of Illumination	128.02°
θ_s	Secondary Angle of Illumination	7.16°
2c	Distance between Primary and Secondary Focus	6.177 m
H	Depth of Primary	1.875 m
V	Primary Vertex Hole Clear Aperture	0.75 m

Table 4.3.2-1: Optical configuration parameters of the antenna

The overall optical layout of the antenna is given in Figure 4.3.2-a.

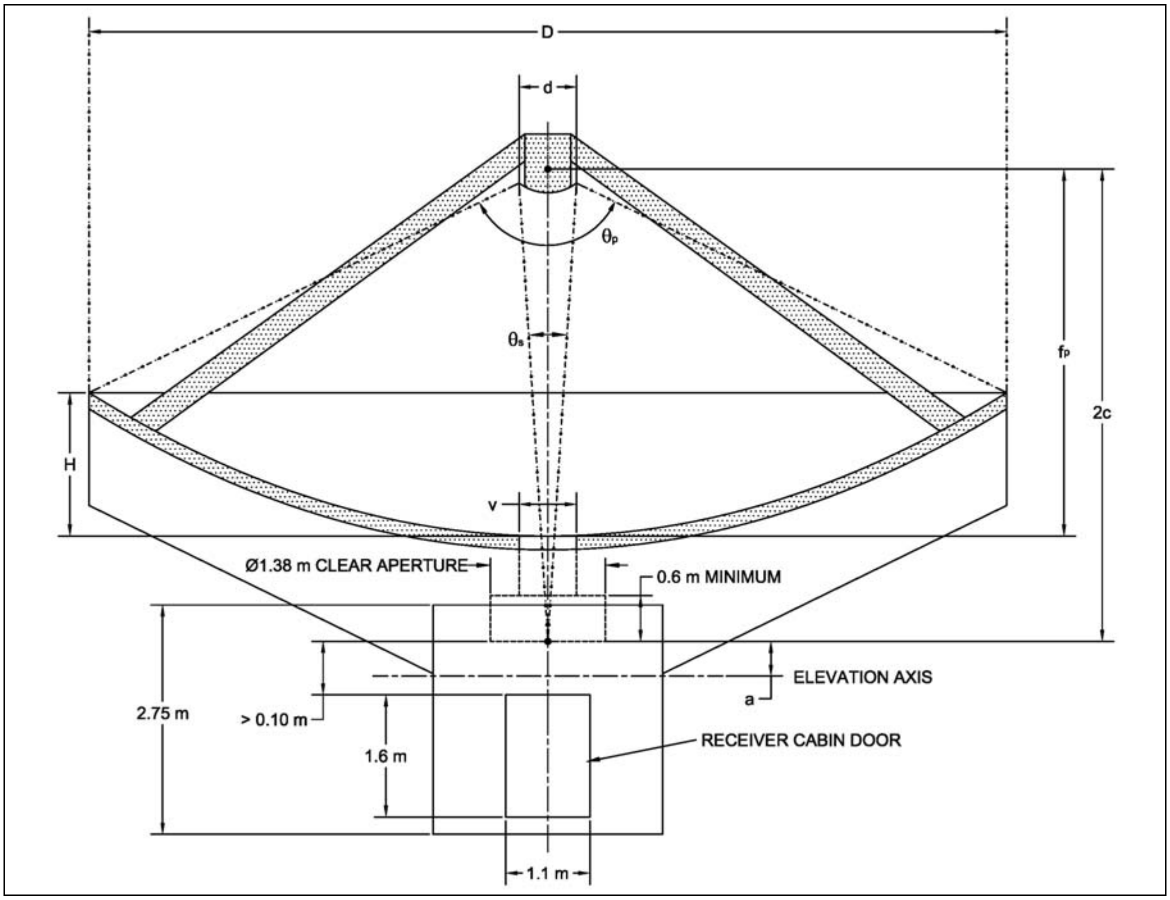


Figure 4.3.2-a: Optical configuration of the antenna.

4.3.3 ALLOWABLE DESIGN VOLUME

The following requirements apply to the antenna volume:

4.3.3.1 Close packing

It shall be possible to locate two antennas with their azimuth axes within 15 meters of each other without any possibility of the antennas colliding with each other, no matter what the relative orientation of the two antennas.

4.3.3.2 Height

The height of the antenna pedestal shall be such that the edge of the primary reflector in no case will be closer than 1 meter to the level of the upper surface of the antenna station.

The elevation axis of the antenna shall not be higher than 7600 mm above the antenna pad level ($Z_p \leq 7600$ mm).

4.3.4 ANTENNA VOLUME DURING TRANSPORT

During transport and relocation the volume of the antenna being transported shall comply with the requirements of applicable document DWG02.

While the antenna is on the antenna station it shall be possible to define a position which complies with the volume clearance and volume requirements of DWG02 (see also Section 5.2.4).

4.3.5 MASS

The mass of the antenna shall be minimized to the extent possible, without prejudice to the other performance specifications.

The total mass of the antenna shall not exceed 105000 kg. This value does not include the equipment supplied by ALMA.

The characteristics of the masses supplied by ALMA are defined in the relevant ICDs and interface requirements.

4.3.6 LOCATION OF THE CENTER OF MASS

The location of the center of mass of the antenna once mounted on the antenna station shall satisfy the requirements of applicable document DWG01.

4.4 OPERATING PARAMETERS AND CONDITIONS

4.4.1 APPLICABLE ENVIRONMENTAL CONDITIONS

Environmental conditions for the ALMA Antenna as defined in AD [2] are fully applicable except where otherwise herein specified.

Of particular importance for the present Technical Specification are <u>all the environmental conditions linked to the altitude of the AOS (5000m)</u> where the antenna will be operated. The specific applicable conditions are to be found in AD [2]

4.4.2 OPERATING CONDITIONS: GENERAL

Various operating and maintenance conditions as well as accidental loading conditions have to be expected during the lifecycle of the antenna[3]. They are:

<u>Primary operating conditions</u>:
These are the conditions under which science observation can be performed having full performance of the antenna.

<u>Secondary operating conditions</u>:
These are the conditions under which science observation can be performed but the antenna performance can be degraded.

<u>Stow conditions survival:</u>
These are the atmospheric conditions under which the antenna will stop operating and it will be parked (stowed) in a safe position. Once the stow conditions survival are finished the antenna shall not have any permanent degradation.

<u>Transport Conditions</u>:
These are the conditions under which the antenna will be transported between the OSF and the AOS and relocated between antenna stations

<u>Accidental conditions</u>:
These are occasional accidental conditions of different severity which may be experienced by the antenna during its lifetime. The antenna must be able to survive these events and be able to restart operation after their occurrence with no or limited manpower.

<u>Stow Condition maintenance</u>:
This is the orientation at which the antenna will be parked in order to perform maintenance. It does not correspond to a specific set of loadings on the antenna but just to a parking position.

[3] These conditions should not be confused with the ACU Modes of Operation as defined in Section Cable Wrap ANTD-34-00.00.00.-004-A-DWG} of the present specification.

4.4.3 PRIMARY OPERATING CONDITIONS

For the purpose of computing the performance of the antenna the Contractor shall assume the following conditions:

Ambient temperature T: -20 ºC < T < 20 ºC.

Wind and thermal conditions:

Daytime:

- Wind: 6 m/s average wind, spectral content to be obtained by scaling the Simiu spectrum, S(u), shown in Figure 4.4.3-1. Equivalent wind speed, including the effect of wind gusts, to be used for quasi-static calculations, shall be 6.4 m/s. For dynamic calculations, two cases are to be analyzed: 6 m/s average wind with variable component S(u); 6 m/s average wind with variable component 4*S(u).
- Solar flux: Full solar heating from any direction, Solar flux up to 1290 W/m^{2}.
- Tº gradients: Temperature change in ambient air temperature in 10 minutes 0.6 ˚C, change in ambient air temperature in 30 minutes 1.8 ˚C

Nighttime:

- Wind: 9 m/s average wind, spectral content is the Simiu spectrum, S(u), shown in Figure 4.4.3-1. Equivalent wind speed, including the effect of wind gusts, to be used for quasi-static calculations, shall be 9.5 m/s. For dynamic calculations, two cases are to be analyzed: 9 m/s average wind with variable component S(u); 7 m/s average wind with variable component 4*S(u).
- Tº gradients: None.

Precipitation: None

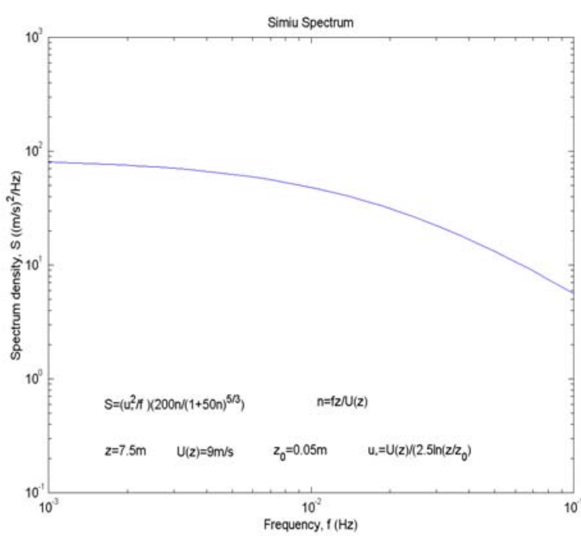


Figure 4.4.3-1: Wind Spectrum for the AOS Site, 9 m/s average wind speed.

4.4.4 SECONDARY OPERATING CONDITIONS

Observations with the antennas will continue to be possible under the conditions herein specified. It is understood that system performance of the antenna may be degraded (pointing, surface accuracy, delay). The conditions do not need to occur simultaneously.

- Ambient temperature T: + 20ºC ≤T ≤ 30 ºC
- Wind speed: 10 m/s < v ≤ 20 m/s
- Precipitation: none

4.4.5 SURVIVAL STOW CONDITIONS

The antennas will be stowed under any of the following conditions:

- Ambient temperature: T ≤ -20 C
- Wind: v > 20 m/s.
- Precipitation: rain, snow or icing

For the purpose of the analysis of the ability of the antenna to survive these conditions the following specific conditions are defined: The conditions are to be considered independently except for the cases of ice loading and survival wind conditions, which are to be survived simultaneously.

4.4.5.1 Survival Wind conditions

Wind: 65 m/s with the antenna in the Stow position for survival with elevation and azimuth stow pins in, wind from any azimuth direction.

The survival wind conditions are classified as an event with a level **C** Hazard Probability.

4.4.5.2 Survival Temperature Conditions

Bulk ambient temperature = -30 ˚C, antenna in stow position.

4.4.5.3 Survival Precipitation Conditions

- Rainfall 50 mm/hr
- Hailstones 2 cm diameter, v= 25 m/s,
- Radial ice on all exposed surfaces 1 cm thick antenna in any orientation
- Snow 100 kg/m2 on reflector, pointing zenith

It is not required that the reflector surface is heated up to prevent snow and ice buildup.

4.4.5.4 Lightning

Direct lightning strike, and lightning electromagnetic pulse (LEMP) conditions apply, with the antennas in any orientation.

Lightning is classified as an event with a level **A** Hazard Probability.

Lightning protection requirements can be found in section 6.12.3 of this specification.

4.4.6 TRANSPORT CONDITIONS

The loading conditions which the antenna is encountering during transport are specified in applicable document ICD [03]. These loads will be transmitted through the transport attachment flanges. Accidental loads like shocks at the base of the antenna when setting the antenna down are defined in Section 4.4.7.2 of the present specification.

4.4.7 ACCIDENTAL CONDITIONS

These define the accidental loads which may be experienced by the antenna during its operational life. The Antenna does not have to fulfill its operational performance requirements during the occurrence of these events. However the antenna shall be able to survive these events and it shall be possible to put it back in operational condition with a limited amount of repair and/or realignment work.

The accidental events are classified in terms of their probability of occurrence according to the levels defined in table 8.3.2.2. The evaluation of the acceptability of the effects generated by the accidental events has to be done in accordance with section 8.3.2.3of the present specification.

The accidental conditions are defined by the individual load-cases defined hereafter. No combination of the accidental loads shall be considered, unless specified in Section.9.1.

4.4.7.1 Seismic Conditions (MLE)

The Maximum Likely Earthquake (MLE) is defined in the Environmental Specification (AD [2]). It is an earthquake of large magnitude but with low probability of occurrence during the lifetime of the observatory.

The earthquake is defined in terms of ground acceleration response spectra at the telescope pillar base. The MLE Response Spectra to be used for the design and analysis of the antenna is given in Appendix 1 of AD [2] (Environmental Specification). The damping ratio which shall be used is 1.5% of critical damping.

The earthquake can occur with the antenna in any position.

The MLE is classified as an event with a level D Hazard Probability, as defined in Section 8.3.2.2.

4.4.7.2 Transporter Handling Shock

Transporter Handling (antenna is in zenith position): accident during set-down on the foundation, 4g vertical impact on the antenna base of short duration; accident during transport on transporter, 2g horizontal impact on the antenna base of short duration.

The handling shock is classified as an event with a level C Hazard Probability, as defined in Section 8.3.2.2.

4.4.7.3 Emergency Braking

Activation of the azimuth or elevation brakes when the antenna is moving at its maximum velocity (3 deg/s elevation velocity, 6 deg/s azimuth velocity, as per Section 5.2.1), antenna in any position.

The emergency braking is classified as an event with a level B Hazard Probability as defined in Section 8.3.2.2.

5 ANTENNA SYSTEM REQUIREMENTS

5.1 OPERATING FREQUENCY RANGE

The operating frequency of the antenna shall be 30 GHz to 950 GHz.

5.2 MOUNT REQUIREMENTS

The antennas shall be equipped with an Altitude over Azimuth mount. The requirements on the axis movements are given below:

Range requirements:

- Minimum Azimuth axis range: -270 to +270 degrees from +Yp axis
- Observing range elevation axis: +2 to 90 degrees
- Maximum size of keyhole centered on the Zenith (blind spot, solid angle) when tracking at sidereal rate 0.4 degrees

The ranges on Elevation and Azimuth axes shall extend beyond the observation ranges, but shall be limited by software and hardware limits, as well as by hard stops, as specified in Section 6.2.4. The maximum ranges shall not extend beyond the limits below:

- Maximum elevation axis range (kinematical range) -1.5 to 93.5 degrees
- Maximum azimuth range (kinematical range) -275 to + 275 degrees

5.2.1 VELOCITY AND ACCELERATION

It shall be possible to move the antenna with the following speed and acceleration:

- Maximum Azimuth angular velocity: $\geq$ 6 deg/s
- Maximum Elevation angular velocity $\geq$ 3 deg/s
- Maximum Azimuth angular acceleration $\geq$ 18 deg/ s^2
- Maximum elevation angular acceleration: $\geq$ 9 deg/ s^2

Both these axes must be able to achieve these rates simultaneously.

Note: The above accelerations and speeds are the minimum required by ALMA. In case the specific design adopted by the Contractor demands higher accelerations and/or speed in order to comply with the Fast Motion requirements of Section 5.4 of the present Specification, the higher values shall be applicable.

5.2.2 STOW POSITIONS

It shall be possible to stow the antenna in two different positions, one used in case of occurrence of the survival atmospheric conditions, and the other in case of specific maintenance to be performed on the antenna.

- Stow position for Survival Conditions shall be 15 degrees elevation, 90 degrees azimuth.
- Maintenance stow position shall be 90 degrees elevation, 90 degrees azimuth.

5.2.3 TRANSPORT POSITION

The antenna will be removed from the antenna station, transported and installed on the station with the elevation angle = 90 degrees.

5.2.4 CLOSE PACKING PARK POSITION

It shall be possible to park the antenna in a position which is compliant with the volume requirements of DWG [02], in order to allow the loaded antenna transporter to have sufficient clearance when the antennas are closed packed. The following applies:

- Azimuth position — user definable
- Elevation angle — defined by Contractor

5.2.5 ANTENNA ALIGNMENT REQUIREMENTS

5.2.5.1 Azimuth Axis

The azimuth axis of the antenna as obtained by the rotation of the azimuth bearing shall never deviate more than 15 arcsec from the Zp axis

The instantaneous position of the azimuth axis of the antenna for a complete turn of the azimuth bearing shall not move in space more than +/-15 micrometers, measured at the level of the Azimuth bearing.

5.2.5.2 Elevation Axis

The instantaneous position of the elevation axis of the antenna for a complete turn of the elevation bearing shall not move in space more than +/-5 micrometers, measured at the level of the two elevation bearings.

5.2.5.3 Azimuth and Elevation Axes Offset

The offset between the azimuth and elevation axes shall be limited by:

- Maximum distance between the axes: — 1.0 mm
- Maximum orthogonality error between axes — 0.5 arcminute

The offset between the two axes over temperature range of -20 ºC < T < 20 ºC and a period of 9 months shall not vary more than 30µm. This includes transport of the antenna, but not transporter handling shock.

5.2.5.4 Reflector Axis and Elevation Axis Offset

The axis of symmetry of the primary reflector does not need to intersect the elevation axis. The offset between the two axes shall be limited by:

- Maximum distance between the axes: 1.0 mm
- Maximum orthogonality error between axes 0.5. arcminute

5.2.6 SUBREFLECTOR STABILITY

When moving between elevation 90 degrees and elevation 0 degrees, the movement of the subreflector in the Reflector coordinate system shall comply with the following:

- Maximum lateral displacement $\Delta Y_R \leq 2.0$ mm
- Maximum rotation around the X_R axis ≤ 0.2 degrees
- Maximum displacement around the Z_R axis $\Delta Z_R \leq 2.0$ mm

Note: The above displacements are the maximum allowed by ALMA. In case the specific design adopted by the Contractor demands smaller values in order to comply with the pointing, delay and surface error budgets, the smaller values shall be applicable.

5.3 ANTENNA POINTING AND TRACKING REQUIREMENTS

The pointing error is defined as the difference between the commanded position of the antenna and the actual position of the RF beam of the antenna. Pointing errors are classified as repeatable and non-repeatable.

5.3.1 REPEATABLE POINTING ERRORS

Repeatable pointing errors are caused by gravity deformation, axis alignment errors, encoder offsets, bearing runout, bearing alignment, and similar errors, which do not vary with time, can be measured and can be corrected using a computer pointing model.

The uncorrected repeatable pointing error for the antenna mount when pointing to any object within the observing azimuth and elevation range shall not exceed 1.5 arcminute (peak value).

5.3.2 NON-REPEATABLE POINTING ERRORS

Non-repeatable pointing errors are pointing errors that vary with time or are not-repeatable as a function of antenna position. Such pointing errors are due to wind, effects of temperature differences and temperature changes, acceleration forces, encoder resolution, encoder errors, servo and drive errors, position update rate, bearing-non-repeatability and other similar sources.

Non-repeatable pointing errors which are "systematic" in the sense that the pointing error is likely to be the same for all antennas and approximately constant in time are much more damaging to the performance of the ALMA array than pointing errors which are random amongst antennas and time variable. In the pointing error budget the Contractor shall give preference to the possible extent to minimizing "systematic" pointing errors in preference to sources of error which are likely to be random amongst antennas and variable in time.

The Contractor may include metrology equipment in the antenna design to provide active correction for some of these error sources and the contribution to the pointing error budget for such corrected error sources may be reduced accordingly.

The pointing error is specified for two different kinds of pointing, "offset" and "absolute" pointing.

5.3.2.1 Absolute Pointing Errors

In the case of "absolute" pointing error the only limitation to slowly varying errors which can be accounted for in the error budget is a once a month recalibration of the pointing model.

The non-repeatable pointing error under Primary Operating Conditions for "absolute" pointing on the whole sky shall not exceed 2.0 arcsec RSS when computed according to the requirements of Section 5.3.2.3. This requirement does not apply if pointing is performed during fast motion as per Section 5.4.

Elements of the error budget provided by the Contractor will be tested with the optical pointing telescope after implementation of a pointing model, according to the requirements of ICD [06]. The RSS value of these elements of the error budget will be verified by taking the RMS of a series of measurements performed with the Optical Pointing Telescope

5.3.2.2 Offset Pointing and Tracking Errors

For "offset" pointing and tracking the contribution to the error budget for slowly varying causes of pointing error, but not for wind induced errors, shall be limited to the accumulated error when the antenna is:

- pointed within 2 degrees from any starting position, and
- tracking over a 15 minute period at sidereal rate.

It shall apply:

The non-repeatable "offset" pointing and tracking error under Primary Operating Conditions (section 4.4.3) shall not exceed 0.6 arcsec RSS when computed according to the requirements of Section 5.3.2.3.

Elements of the error budget provided by the Contractor will be tested with the optical pointing telescope after implementation of a pointing model, according to the requirements of

ICD [06]. The RSS value of these elements of the error budget will be verified by taking the RMS of a series of measurements performed with the Optical Pointing Telescope

5.3.2.3 Computation of the Non-repeatable Pointing Errors

In order to compute the non-repeatable pointing errors, error budgets shall be established which take into account all the expected sources of error generated by the design selected. The error budgets shall sum quadratically (RSS) the various contributions as long as the individual error sources can be considered uncorrelated.

Contributions to the error budgets which have a random nature (example control errors) shall be included in the RSS error budget as a RMS value.

An example of a possible error budget is given in Table 5.3.2.3.b. Wind and temperature effects may be partially corrected by incorporating information from an antenna metrology system (see Section 5.3.2).

a) Computation of the wind induced error:

Calculate the quasistatic pointing error for each of the eleven wind directions shown in table 5.3.2.3-a, with the average wind speed defined for the Primary Operating conditions. Compute the weighted RMS of these eleven wind directions with the weighting factors defined in the table to obtain the steady state component of the wind.

The gust component of the wind can be computed by scaling the quasistatic values obtained for the steady state.

Azimuth Angle (deg)	Elevation Angle (deg)	Weighting Factor
0	0	.031
60	0	.062
120	0	.062
180	0	.031
45	45	.188
135	45	.188
0	60	.094
90	60	.188
180	60	.094
90	90	.031
0	90	.031

*Assume that the wind is blowing in direction 180 deg. Thus the case azimuth 0, elevation 0 corresponds to the reflector being faced into the wind.

Table 5.3.2.3-a: Antenna Orientations for Wind Pointing and Path Length Error Calculations

b) Computation of the thermal effects (daytime)

For daytime Primary Operating Conditions a computer thermal model of the antenna shall be used to determine the worst case non-repeatable pointing error due to temperature differences and temperature changes in the structure. The structural temperature differences shall be calculated using a computer thermal model, assuming a wind speed of ≤ 5 m/sec

c) Computation of the Nighttime pointing error budget

The nighttime pointing error budget shall be the quadratic sum (RSS) of all the individual sources of pointing error including the steady state and gust wind contribution according to the Primary Operating Conditions of Section 4.4.3. No thermal effect contribution shall be included in the nighttime error budget.

d) Computation of the Daytime pointing error budget

The daytime pointing error budget shall be the quadratic sum (RSS) of all the individual sources of pointing error including the steady state and gust wind contribution according to the Primary Operating Conditions of Section 4.4.3 and the thermal effects contribution.

The daytime thermal pointing error is defined to be 75 percent of the thermal effects on pointing computed for the worst case under point b) above.

Non-Repeatable Pointing Error (arcsec)	**Day**	**Night**
Wind, steady component	.2	.45
Wind, gusty component	.1	.1
structure temperature gradients	.35	0.0
Ambient temperature changes	.2	0.0
inertial forces	.15	.15
Encoder errors	.2	.2
Servo error	.1	.1
bearing errors	.2	.2
Other errors	.19	.19
Total RSS error	.60	.60

Table 5.3.2.3-b: Example of pointing error budget

5.4 FAST MOTION CAPABILITY

The antennas will be used to point at astronomical sources and track them across the sky at sidereal rate. Three observing modes require the ALMA antennas to have special fast motions superimposed on the slow sidereal tracking rate. These fast motion modes are "*fast switching phase calibration*, *on-the-fly total power mapping* and *on-the-fly interferometric mosaicking*.

5.4.1 FAST SWITCHING PHASE CALIBRATION

Fast switching phase calibration requires the antenna to move from the target source to a calibration source up to 1.5 degrees away on the sky.

For design purposes, in the fast switching cycle to be considered here, the antenna shall perform steps of 1.5 degrees on the sky and settle to within 3 arcsec peak pointing error, all in 1.5 seconds of time. The antenna shall then track and integrate on a calibration source during one second, then it shall switch back to the target source with the same requirements on switching time and settling accuracy. It shall then track on the target source. The time for a full cycle of target-calibrator-target observation shall be 10 seconds.

The antenna may spend many hours cycling in this way. For the purpose of the dimensioning of the drives and of the cooling system continuous operation of the antenna shall be assumed.

5.4.2 ON THE FLY TOTAL POWER MAPPING

During on the fly total power mapping the antenna will scan across a target source ranging from one arcmin to one degree in size, then turn around and scan back across the source, at speed up to 0.5.deg/s.

For design purposes, in on the fly total power mapping profile to be considered here, the antenna shall scan at a rate of 0.5 deg/s on the sky across a target source of one degree in size, then turn around at a distance of 1 arcmin, settle within 0.8 sec time and scan back across the source in the opposite direction with a 2 arcsec RMS accuracy within primary operating conditions (as provided by the encoders reading, corrected with any metrology). This performance shall be attained up to 60 degrees elevation.

5.4.3 ON THE FLY INTERFEROMETRIC MOSAICKING

In on-the-fly interferometric mosaicking, the antenna will scan at a rate of up to 0.05 deg/s on the sky across a target source, ranging from one arcmin to one degree in size, and then turn around and scan back across the source in the opposite direction.

For design purposes it shall be considered that during the scans across the source the antenna shall follow the commanded path to within 1 arcsec RMS, within primary operating conditions (as provided by the encoders reading, corrected with any metrology).

5.4.4 STEP RESPONSE

If a step change in position is commanded, the direction of the boresight axis shall fulfill the following:

Step amplitude (sky)	1.5 degrees
Accuracy	3 arcsec, within 1.5 sec, *and* 0.6 arcsec, within 2.0 sec (total)

This applies to the motion on the sky and in any direction, except that the azimuth component of the motion need only meet this requirement if the elevation is less than 60 deg.

5.5 ANTENNA SURFACE ACCURACY REQUIREMENTS

The total antenna surface accuracy during Primary Operating Conditions shall be < 25 micrometers Root-Sum-Squared (RSS).

The total antenna surface accuracy budget shall include contributions from both primary reflector and the subreflector. Factors contributing to the error budget are shown in the example error budget shown in Table 5.5-1.

The error budget shall allocate 10 micrometers RMS for the holographic measurement accuracy and 2 micrometers RMS for the panel setting accuracy perpendicular to the plane of the reflector surface, as shown in Table 5.5-1.

All other contributions in the error budget can be varied depending on the specific design adopted provided that the RSS total is less than 25 micrometers.

The errors for panels shall be calculated by taking root mean square (RMS) of the component along the boresight axis of the normal-to-surface deviations between the theoretical paraboloid and the deformed panel surface without fitting. (This does not exclude fitting measured data to eliminate measurement reference errors when determining the panel manufacturing error.)

Backup structure (BUS) gravity errors shall be calculated by taking the RMS of the component along the boresight axis of the normal-to-surface deviations between the deformed surface and the best fit paraboloid. For calculating gravity induced errors, it is possible to select the elevation angle at which the surface is set which provides the best overall performance (rigging angle).

While calculating the effect of thermally induced error on the BUS and other slowly varying errors it shall be assumed that the antenna is refocused every 30 minutes.

The errors of the subreflector shall be calculated by taking the RMS of the component along the boresight axis of the normal-to-surface deviation between the deformed, non-ideal surface and the best-fit hyperboloid.

Allowance for aging (creeping, etc.) shall be made in the error budget of Table 5.5-1 under the item “Backing Structure.” An illumination amplitude edge taper of -12dB that is properly weighted to the collecting area can be assumed for calculating the reflector surface accuracy. Best fitting of the focal length of the DC component of wind is not permitted.

In calculating the reflector surface accuracy the Contractor shall use the larger contribution of:

a) full wind effect (computed taking into account the various wind directions and weighting factors provided in Section 5.3.2.3) and no thermal contribution

b) full thermal contribution and no wind.

Error Source	RMS Error
Panels	
Manufacturing *(Including measurement errors)*	8.5 µm
Aging	2.0 µm
Gravity	4.0 µm
Wind	4.0 µm
Absolute Temperature	4.0 µm
Temperature Gradients	4.0 µm
Total Panel (RSS)	**11.8 µm**
Backing Structure	
Gravity (Ideal)	9.0 µm
Gravity (Departure from Ideal)*	3.0 µm
Wind	4.0 µm
Absolute Temperature	8.0 µm
Temperature Gradients	7.0 µm
Aging	2.0 µm
Total Backing Structure	**14.8 µm**
Panel Mounting	
Absolute Temperature	3.0 µm
Temperature Gradients	3.0 µm
Panel Location in Plane	3.0 µm
Panel Adjustment Perpendicular to Plane***	2.0 µm
Gravity	5.0 µm
Wind	4.0 µm
Total Panel Mounting (RSS)	**8.5 µm**
Secondary Mirror	
Manufacturing	5.5 µm
Gravity	2.0 µm
Wind	2.0 µm
Absolute Temperature	4.0 µm
Temperature Gradients	4.0 µm
Aging	3.0 µm
Alignment	3.0 µm
Total Secondary Mirror (RSS)	**9.4 µm**
**Holography measurement ** **	10.0 µm
Total Holography (RSS)	**10.0 µm**
Other Errors not Included Above	2.0 µm
TOTAL (RSS)	**25.0 µm**

** Departures from ideal such as member true size, manufacturing, modeling accuracy, etc.*
*** ALMA is responsible for this element of the error budget of the primary reflector surface.*
****The panel adjustment perpendicular to plane of the primary surface is fixed at 2µm)*

Table 5.5-1: Example of Surface Accuracy Budget

5.6 PATH LENGTH ERROR

Path length errors must be considered since the antennas will be used in an array. Path length (also called delay) errors are defined as follows. Consider a plane wave arriving at the antenna from the direction of the boresight. Define the "excess delay" of the antenna to be the difference between the arrival time of that wave at the secondary focus (via the main reflector and subreflector) and its arrival time at an arbitrary reference point fixed with respect to the ground as if the antenna were not present. (It is convenient to choose the reference point along the azimuth axis. If the boresight axis, elevation axis and azimuth axis all intersect, then choosing that intersection as the reference results in an excess delay that is nearly constant.) The excess delay (expressed as a path length) for the nominal antenna in the absence of environmental perturbations, shall be computed as a function of boresight direction over the full range of azimuth and elevation. This shall be defined as the “nominal excess delay function.” Now define the “residual delay” as the difference between the actual excess delay of a particular antenna under existing conditions and the nominal excess delay. The residual delay is limited by the specifications of this section. The residual delay has a repeatable and a non-repeatable component.

5.6.1 REPEATABLE RESIDUAL DELAY

The repeatable residual delay is caused by the difference in gravity deformation between an antenna and the nominal antenna (for example, this could be caused by differences in the material properties of an antenna compared to the nominal material properties), axis alignment errors, bearing runout, bearing alignment, and similar errors, which repeat as a function of antenna position and can be corrected using a computer delay model.
It applies:

The repeatable residual delay for an antenna shall not change by more than 20 micrometers when the antenna moves between any two points 2 degrees apart in the sky.

5.6.2 NON-REPEATABLE RESIDUAL DELAY

The non-repeatable residual delay is the delay component that varies with time or is not repeatable as a function of antenna position. It is caused by wind, effects of temperature differences and temperature changes, acceleration forces, bearing non-repeatability and other sources of non-repeatable errors. The Contractor may include metrology equipment in the antenna design that can be used to estimate the residual delay in real time. In that case, both the measured values and the results of a calculation estimating the residual delay shall be provided to ALMA via the digital interface (see Section 6.10.5.1). If this is done, then the estimate shall be subtracted from the actual residual delay for the purpose of meeting the specifications of this section. Further, for slowly varying sources of residual delay, but not for wind induced residual delay, the contribution to the residual delay budget may be limited to the differential residual delay over a solid angle of 2 degrees radius on the sky and then only the change in that differential delay over a 3 minute period when tracking at the sidereal rate.

The non-repeatable residual delay under Primary Operating Conditions (section 4.4.3) must be less than 15 micrometers RSS when tracking an astronomical source at sidereal rate.

5.6.3 COMPUTATION OF THE NON-REPEATABLE RESIDUAL DELAY

The non-repeatable residual delay shall be computed both for nighttime and daytime conditions by use of error budgets.

a) Computation of the wind induced delay:

Calculate the quasistatic delay error for each of the eleven wind directions shown in Table 5.3.2.3-a, with the average wind speed defined for the Primary Operating conditions. Compute the weighted RMS of these eleven wind directions with the weighting factors defined in the table to obtain the steady state component of the wind.

The gust component of the wind can be computed by scaling the quasistatic values obtained for the steady state.

b) Computation of the thermal effects (daytime)

For daytime Primary Operating Conditions a computer thermal model of the antenna shall be used to determine the worst case non-repeatable delay error due to temperature differences and temperature changes in the structure. The structural temperature differences shall be calculated using a computer thermal model of the antenna, assuming a wind speed of ≤ 5 m/sec

c) Nighttime residual delay

The nighttime residual delay shall be the quadratic sum (RSS) of all the individual sources of delay including the steady state and gust wind contribution according to the Primary Operating Conditions of Section 4.4.3. No thermal effect contribution shall be included in the nighttime error budget. The effect of the steady state and gust wind shall be computed according to the methodology and with the weighting factors of Section 5.3.2.3.

d) Daytime residual delay

The daytime pointing residual delay error shall be the quadratic sum (RSS) of all the individual sources of delay error including the steady state and gust wind contribution according to the Primary Operating Conditions of Section 4.4.3 and the thermal effects contribution.

The effect of the steady state and gust wind shall be computed according to the methodology and with the weighting factors of Section 5.3.2.3.

The daytime thermal residual delay is defined to be 75 percent of the thermal effects on delay computed for the worst case under point b) above.

5.7 SOLAR OBSERVATIONS

Continuous, direct observations of the sun shall be possible while meeting all performance specifications. In order to achieve this, the primary surface, which will not be painted, shall have a suitable scattering surface treatment. A similar provision may be needed for the surface of the subreflector. Under no conditions solar heating may damage any part of the antenna.. This applies also to the case when the sun is close to the boresight or the antenna is pointing directly at the sun. The panel surface treatment needs to be validated by panel sample tests.

When the antenna is pointed directly at the center of the sun, or near the sun, the power absorbed by a black body anywhere in the secondary focal region shall not exceed 0.3 W/cm2.

5.8 LOW NOISE

Contributions to system noise from the antenna, due to resistive loss of the primary reflector surface and scattering of ground noise into the feed, shall be minimized as much as possible without compromising the surface accuracy and pointing requirements. Design features will include supporting the quadripod legs close to the edge of the reflector and equipping the underside of the support legs with a wedge shaped profile to minimize ground noise pickup, as specified in Section 6.8.4.

The primary reflector surface and the secondary mirror shall each have a surface resistive loss of less than 1.0 percent over the operating frequency range (Section 5.1) of the antenna.

The total unweighted geometrical blockage shall not exceed three percent (3%). The contribution to the geometrical blockage shall include: subreflector, vertex hole in the primary, quadripod legs, panel gaps, holes in the panels for access to the panel adjusters, the optical pointing telescope hole, panel gaps and any design feature which will contribute to the blockage.

5.9 TRANSPORTABILITY

The antennas shall be specifically designed to be transportable. The antennas will be transported on a transporter vehicle, which will be designed and provided by ALMA. Specific requirements related to the transportability of the antenna are spelled in ICD [03] as well as in DWG [01].

In particular the interface flanges to the Transporter shall be located at Zp higher than the azimuth bearing so that the azimuth bearing and drive can be used to rotate the base of the antenna for aligning the antenna onto the antenna stations, while the antenna is suspended by the transporter. The antenna base shall be able to be rotated (under power) in the full azimuth range while on the transporter.

The antenna must be designed to minimize the amount of time that it takes to make and break the connections between the antenna and the foundation and the antenna and the transporter. All connections and interfaces to the transporter and stations must be removable in less than 15 minutes and installable in less than 20 minutes. This shall include all setting and calibrating of metrology instruments, and removal and installation of platforms or ladders that may be in the way for the attachment of the transporter.

6 SUBSYSTEM REQUIREMENTS

6.1 FOUNDATION REQUIREMENTS

Contributions from the foundation at the antenna stations shall be taken into account in the performance of the antenna and included in the error budgets in order to demonstrate compliance with the specifications.

The Contractor must ensure that the antenna in conjunction with the foundation provides the performance required by his/her error budget. The design of the antenna shall include all connections between the station and antenna as per ICD [01].

The minimum stiffness and load capability of the foundation are provided in ICD [01]. The finite stiffness of the combined soil and foundation shall be included in the dynamic analysis of the antenna.

The design of the connection to the antenna stations and the repeatability of positioning provided by the attachment shall be taken into account in the verification of the alignment of the azimuth axis as per Section 5.2.5.1.

6.2 ANTENNA MOUNT SYSTEM

6.2.1 BASE

A door in the base of the antenna shall be provided for personnel to walk into the space located inside the base. The door shall be latchable open, and lockable. The condition of "door open" shall be monitored by the ACU.

The base shall be equipped with sufficient lighting to perform maintenance work as well connection and disconnection from the antenna station. At least 2 single-phase socket-outlets shall be located in the base at locations approved by ALMA. These socket-outlets shall be fed by 'normal' power (non-UPS) and shall conform to section 4.2 of AD [4]('Schuko' socket-outlets).

The antenna base shall be flush with the station concrete surface and there shall be a sealing gasket to prevent animal and precipitation intrusion.

In the design of the base, the access and the location of the equipments, the Contractor shall take into account ergonomic principles.

6.2.2 MAIN AXES DRIVES

The drives of the elevation and azimuth axis shall be dimensioned in order to provide the following performances:

- All the relevant system requirements of Section 5.
- Ability to bring the antennas to stow with wind up to 30 m/s with half of the torque provided by the system (one faulty drive in case of gear and pinion drive, half of the linear motors in case of a linear direct drives).
- It shall be possible to drive the antennas to stow in a rainfall rate of 2 cm/hr, with a snow accumulation of 50 kg/m^2 in the reflector or with an ice load of 1 cm radial ice on all exposed surfaces, and
- It shall be possible to drive and stow the antenna in the survival stow position when the ambient temperature is in the range -25 ˚C to +30˚C

The power used by the antenna drives during acceleration and deceleration shall be minimized.

6.2.3 MAIN AXES BRAKES

The elevation and azimuth axis shall be equipped with brakes. The brakes shall be:

- Fail safe
- Redundant
- Able to stop the antenna at the maximum speed within 0.5 sec.
- Able to prevent motion with the maximum torque applied to the motors
- Able to keep the antenna in any parked position and with wind up to 30 m/sec.

The deceleration caused by the brakes, also if operated at maximum speed shall not cause damage or need for realignment of the antenna.

6.2.4 AXES LIMITS AND STOPS

The elevation and azimuth axes movement ranges shall be limited outside the observing ranges by pre-limits, final limits and hard stops as specified herein.

6.2.4.1 Software limits

Software limits, based on encoder readings shall be provided at the limit of the observing ranges, preventing commanding the antenna to go beyond the observing ranges.

6.2.4.2 Hardware Limits

Final limits and pre-limits based on hardwired limit switches shall be provided outside the observing range. Their positions of will be chosen so as to stop the antennas before the final limit if it encounters the pre-limit moving at its maximum velocity. Specific implementation requirements are given in Section 6.10.7.

6.2.4.3 Hard Stops

Elevation and azimuth energy absorbing hard stops shall be provided to protect all parts of the antenna as well as the equipment mounted on it from damage when moving beyond the elevation and azimuth final limits.

The energy absorbing hard stops shall be based on passive systems. They shall be dimensioned in such a way to be able to protect the antenna and its equipment from damage if the antenna travels into the hard stop with full velocity and full motor power simultaneously.

The hard stops must survive repeated use and have a lifetime of at least 10 years.

The hardstops shall be chosen so that their performance is not influenced by the low temperature.

6.2.5 STOW PINS

The antenna shall be equipped with motorized stow pins for both azimuth and elevation provided for both the Survival Stow and Maintenance Stow positions 5.2.2.

Stow pin insertion and removal shall not require more than 30 sec.

At least two independent check methods, one software and one hardware, shall be available to guarantee the correct alignment of the stow pin, prior to enabling the insertion of stow pins. Fault detection by the ACU shall be included in the system.

6.3 RECEIVER CABIN

A receiver cabin room for locating the receiver instrument shall be provided at the Cassegrain focus.

6.3.1 PHYSICAL DIMENSIONS AND CHARACTERISTICS

The receiver cabin room shall have a minimum floor surface of 3 by 3 meters square. The maximum amount of floor space used by equipment of the antenna (HVAC, air ducts, pipes,) shall not be more than 0.75 square meters. In case the design of the antenna demands a larger amount of floor space than this, the overall surface of the cabin shall be increased accordingly. The layout of the cabin shall be approved by ALMA.

Any Contractor-supplied equipment located in the receiver cabin shall be specifically approved by ALMA.

The organization of the space and the location of the equipment in the cabin shall take into account the requirements of the applicable documents ICD [04], and ICD [05]. Ergonomic principle and easiness of access shall be also taken into account.

The floor of the cabin shall be plane without tripping hazards.

The cabin shall be equipped with an entrance whose clear size shall not be less than 1.1 meter wide by 1.6 meters in height. The entrance shall be positioned at negative Y_R coordinate.

Access to the cabin will be done with the antenna positioned at the zenith. The door shall be equipped with water seal and EMC/RFI seal.

The receiver cabin floor must be flush with the external access platform to prevent a tripping hazard and to facilitate transfer of equipment into the Receiver Cabin. Alternatively movable or hinged fixtures shall be used in order to allow an easy transfer of ALMA equipment (example Front End equipment) into the receiver cabin.

Cable trays and attachment points shall be provided in order to accommodate the cabling and the piping as demanded by the applicable documents ICD [04] (Front End) and ICD [05] (Back End). The covers of trays and other opening in the receiver floor shall be removable and flush with the receiver cabin floor.

The mass and center of mass of ALMA installed equipment in the cabin will be according to the requirements of the ICDs.

The receiver cabin shall be water and dust tight.

6.3.2 RECEIVER FLANGE

The cabin will be equipped with a receiver flange as demanded by applicable documents ICD [04]and its associated drawings. Furthermore the ICD [04] provides the mass and the center of mass of the equipment attached to the flange, and the requirements for the alignment and the position stability of the flange.

6.3.3 ELECTRICAL REQUIREMENTS

Adequate work lighting shall be provided in the receiver cabin.

A total of 12 single-phase socket-outlets shall be located in the receiver cabin at locations approved by ALMA. These socket-outlets shall be fed by ‘normal’ power (non-UPS) and shall conform to section 4.2 of AD [4] (‘Schuko’ socket-outlets).

6.3.4 THERMAL REQUIREMENTS

It shall be possible locally at the antenna, and remotely via the ACU, to set the temperature inside the cabin inside the range of 16-22 ˚C, during any of the primary and secondary operating conditions.

In order to achieve this, an antenna mounted HVAC system shall be used. It shall be possible to set and maintain the air temperature with an accuracy of +/-1˚C in the output plenum of the HVAC system. The HVAC system shall be capacity modulated with proportional control. The air distribution system shall utilize continuous air flow to avoid sudden changes in temperature.

The maximum temperature gradients in the air shall not exceed more than 1˚C/hour

The air distribution system shall take into account the fact that the receiver cabin is continuously changing position relative to gravity. The system shall use high-grade air filters.

The outputs of the HVAC plenum will be circulated through two equipment racks as specified by ICD [05], three auxiliary vents as per ICD [04]. In additions at least two room vents will be used to regulate and stabilize the air temperature in the cabin. Each plenum output shall have an adjustable damper.

ALMA will install equipment in the receiver cabin with heat dissipation as per ICD [05] and ICD [04]..

Thermal insulation of the interior cabin walls shall not be used.

All refrigeration piping shall be thermally insulated.

All exposed insulation shall be mechanically protected with a metal cover and weatherproof in exterior applications.

6.3.5 RF MEMBRANE

A thin RF-transparent membrane (Goretex) will cover the aperture through which the RF beam enters the cabin at the vertex hole. The RF transparent membrane will be tilted at an angle of 5 degrees from a plane perpendicular to the boresight axis. The orientation of the 5 degrees inclination shall be settable in steps of 45 degrees in relation to the elevation axis. The change in orientation may be achieved by unbolting and refastening the mechanism from inside the receiver cabin. The mounting of the membrane shall not vignette the free optical space.

The characteristics of this membrane are defined by ALMA. The baseline specification is:

- Type — Radome Material (Goretex))
- Fabric Type: — RA 7956 / RA7957
- Material — 100% fluoropolymer
- Thickness — up to 1.5 mm

The characteristics will be confirmed by ALMA and the Radome material will be provided by ALMA as specified by the Statement of Work.

The membrane shall be protected by a remotely operated metallic shutter, when the receiver is not in use and in case of precipitation (snow, rain, hailstones). Precipitation water entering through the vertex hole in the BUS and reaching the membrane and the space above the cabin shall be evacuated by opening and/or drainage pipes. The drainage system shall be effective also with the Antenna pointing at Zenith.

6.4 REFLECTOR PANELS

The panel shall be manufactured in machined aluminum or by replica technique based on electrodeposited Nickel.

Panels of composite fiber of CFRP are not allowed.

The sum of all panel gaps shall not exceed 0.45 percent of the total area of the reflector.

The panel shall not be painted. A protective metallic coating can be used if this is beneficial in meeting the specification. Any coating used shall be validated under the point of view of RF loss, durability and thermal performance. The overall surface finish and roughness of the panel surface shall be selected in order to meet the solar observation requirements of Section 5.7 and the noise requirements of section 5.8.

The position of the panel shall be adjustable in space by means of panels adjusters connecting the panels to the BUS structure. Access to the adjusters for tuning the surface of the reflector shall be from the front side of the panel via dedicated holes. The holes shall be protected by removable plastic caps preventing intrusion of dust and water once the position has been adjusted.

6.5 PANELS ADJUSTERS

The panels shall be mounted on panel adjusters. The panel adjusters shall guarantee the stability of the panel surface as demanded by the specific design adopted by the Contractor and during all primary operating conditions.

The panel shall have a minimum adjustment range of +/- 5 mm perpendicular to the surface of the reflector.

The adjustment resolution of each adjusters, when loaded with the panel, hence in the final configuration, shall be 5 micrometers or better.

6.6 BACKUP STRUCTURE

The Back Up Structure used to support the panels and the apex shall be principally made of Carbon Fiber Reinforced Plastic or thermally stable composite materials. Other suitable materials may be used in flanges, attachments interfaces, adjusters inserts, fasteners etc.

Access for inspection shall be provided inside the BUS.

6.7 FEED SHUTTER

The vertex hole shall be equipped with a remotely operated metallic shutter. The shutter shall be located above the RF membrane in order to protect it during survival conditions when necessary.

The shutter shall be automatically deployed by the antenna equipment when the antenna is commanded to the survival stow. The shutter shall be capable of being controlled and monitored by the ALMA Antenna Computer. The system shall have status sensors with a manual override. Fault detection by the ACU shall be included in the system.

The feed shutter shall be dimensioned to perform at least 500 cycles per year.

The duration of opening and closing the feed shutter shall not exceed 30 sec.

6.8 APEX EQUIPMENT

The mechanism and support structure behind the subreflector shall be of a smaller outer diameter than the subreflector itself and not protrude outside the subreflector diameter in any translation position generated by the subreflector mechanism.

The apex structure shall be designed so that specifications regarding clearance, mounting and mass as shown in DWG02 are met. Clearance shall take into account the volume of the equipment mounted on the apex, and the travel of the translation stage. The drawing DWG02 defines also an interface cylinder between the subreflector mechanism and the subreflector.

The apex equipment will be subjected to increased heat load and possibly gradients of temperature when the antenna is pointing close to the sun. This shall be taken into proper consideration during the design of the equipment, including routing of cables, insulation material and protection.

6.8.1 SUBREFLECTOR

The contractor shall provide a 750 mm diameter aluminum subreflector that conforms to the optical parameters as set forth in section 4.3.2 and general mounting details specified in drawing DWG [05]. It shall also have a surface accuracy and other associated properties to meet the Contractor's proposed surface accuracy budget of which an example is shown in section 5.5.

It shall have a suitable surface treatment for full solar observations as specified in section 5.6.

6.8.1.1 Subreflector Central Cone

The subreflector shall be equipped with a removable aluminum reflective central cone with characteristics as defined in DWG [04].

6.8.2 SUBREFLECTOR MECHANISM

An ACU controlled mechanism able to translate and position the subreflector in 3 degrees of freedom shall be provided at the apex of the antenna. All three degrees of freedoms shall be equipped with a closed loop servo, limit switches, encoder readouts and shall be monitored.

The control system shall be part of the antenna control system, and be available for monitor and control from ALMA's Antenna Computer. The subreflector control software has to be an integral part of the ACU software, but commercial controllers can be used provided that they do not require any specific software to be developed.

Two translational degrees of freedom will be orthogonal to the optical axis (parallel to X_R and Y_R axes) with travel ranges of +/-5 mm around the nominal position and a positional repeatability and accuracy required by the pointing specification. This range includes the stability requirements of Section 5.2.6 but does not include any misalignment due to the Contractor. The speed achieved in these degrees of freedom in slewing mode shall be at least 0.5 mm/sec. One mode is defined in addition to slewing:

Collimation mode

It shall be possible to perform minimum steps of 20 µm with a differential accuracy of 10 µm.

The third translational degree of freedom is parallel to the optical axis and shall have a travel +/-10 mm from the nominal position. The speed achieved by the system shall be not less than 2.0 mm/sec in slewing. Two modes are defined in addition to slewing:

Focus adjustment mode

It shall be possible to position the subreflector along its range with a repeatability of +/-5 µm.

It shall be possible to perform minimum steps of 20 µm with a differential accuracy of 5 µm.

Focus switching mode

It shall be possible to perform cycles of up to +1.5 mm and –1.5 mm with a positional repeatability of +/-20 µm

For the purposes of dimensioning the system and heat dissipation a continuous operation of the system on cycles of + 1mm step, 10 sec delay, -1mm step (total cycle duration = 22 sec) shall be considered.

6.8.3 Nutator Interface

ALMA will install on the antennas a Nutator that will be used for single dish observation modes. The mass, center of mass position, and the clearance volume are specified in drawing DWG [06]. The cabling requirements are shown in figure 6.9.2-a (except power from the non-critical bus).

An electronic cabinet and its interface to the antenna shall be defined by the Contractor to house the control unit and amplifier of the nutator. This cabinet shall be placed on the azimuth platform or a suitable location outside of the receiver cabin. The nutator power amplifier and controller unit dissipate not more than 1 kW and require 9 U of space in a standard 48cm [19 inch] electronics cabinet.

The cabinet may host additional equipment as shown in figure 6.9.2-a.

6.8.4 Quadripod Structure

The Apex shall be supported by CFRP legs arranged in a quadripod structure.

The support legs of the quadripod shall also be designed to support at least a cable weight of 2 kg/m that can be divided among the subreflector support legs and meet all specifications herein.

All cables routed at the quadripod legs shall be inside metal ducts and/or sheaths, inside the profile of the legs. At least one spare duct shall be available for possible cable additions to the apex..

The undersides of the quadripod legs shall be equipped with a wedge shaped Aluminum profile to minimize ground noise pick up. This profile shall be mounted onto the quadripod leg in such a way that it can occasionally be removed or exchanged. A glued connection is not allowed.

An indicative shape of this is provided in figure 6.8.4.a below.

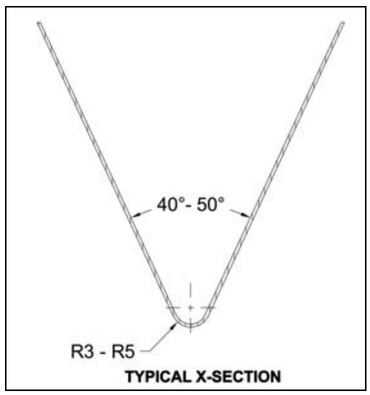


Figure: 6.8.4. a: Shape of the Aluminum profile below the quadripod legs

6.9 CABLE WRAPS AND CABLES

6.9.1 AZIMUTH AND ELEVATION CABLE WRAPS

Cable wraps shall be provided in azimuth and elevation which will accommodate all antenna cables as well ALMA cables and hoses. The cable wraps shall permit full angular rotation of the antenna as specified in section 5.1.1.

The cable wraps shall be such that cables are neither excessively stressed by twisting or bending, nor damaged by pulling over edges of a fixed structure. Specific requirements on bending radii as spelled in ICD [04] and ICD [05] shall be taken into account.

The minimum bending radius of the elevation and azimuth cable wrap shall be in any case larger than 200 mm.

Possible limitation in the amount of torsion which can be sustained by cables and hoses (example: helium lines) shall also be considered.

The design of the cable wrap shall be optimized for durability and reliability taking into account the lifetime requirements of Section 8.1. In case the equipment chosen is not suitable for the complete lifetime of the antenna, substitution of parts is allowed as long as the overhaul requirements of Section 8.2.3.2 are met.

The elevation axes shall have two wraps, one on either side, of which the one located at $-X_R$ coordinate dedicated exclusively to ALMA cables and hoses.

6.9.2 ALMA CABLES AND HOSES

Table 6.9.2-1 lists all ALMA cables and hoses passing through the azimuth cable wrap and table 6.9.2-2 list all the ALMA supplied cables and hoses passing through the ALMA dedicated elevation cable wrap. Both cable wraps shall contain additional required volume for future expandability. An indicative sketch of the ALMA supplied cables and hoses is given in the Figure 6.9.2-a.

Contractor shall provide feed-throughs for all cables from the entrance at the base of the telescope to the inside of the receiver cabin. Two cable/hose feed-through plates will be provided by the Contractor of size 30 cm x 60 cm. The base plate will bolt to the base of the antenna from inside. The second plate is at the receiver cabin and will bolt to the outside of the receiver cabin.

ALMA AZIMUTH CABLE WRAP CABLES			
Qty.	Cable Description	Cable Dia.	Connector Dia.
1 ea.	8 SMF-28 Fiber Cable	12 mm	N/A
2 ea.	Category 5 Ethernet Cable	6 mm	N/A
1 ea.	6 MMF Fiber Cable	9 mm	N/A
1 ea.	4 Twisted Pair CAN Cable	9 mm	N/A
1 ea.	RG-214 Coaxial Cable	12 mm	N/A
6 ea.	Future Cables	12 mm	N/A

Table 6.9.2-1 Azimuth Cable Wrap Cables

ALMA ELEVATION CABLE WRAP CABLES			
Qty.	Cable Description	Cable Dia.	Connector Dia.
7 ea.	Category 5 Ethernet Cable	6 mm	N/A
1 ea.	6 MMF Fiber Cable	9 mm	N/A
2 ea.	4 Twisted Pair CAN Cable	9 mm	N/A
1 ea.	RG-214 Coaxial Cable	12 mm	N/A
1 ea.	3 Pair 16 AWG Cable	12 mm	N/A
1 ea.	8 SMF -28 Fiber Cable	12 mm	N/A
3 ea.	Cryogenics Hose	33 mm	53 mm
1 ea	Cryo Cross-Head Signal Cable	15 mm	42 mm
1 ea	Cryo Compressor Control Cable	15 mm	42 mm
6 ea.	Future Cables	12 mm	N/A

Table 6.9.2-2 Elevation Cable Wrap Cables and Hoses

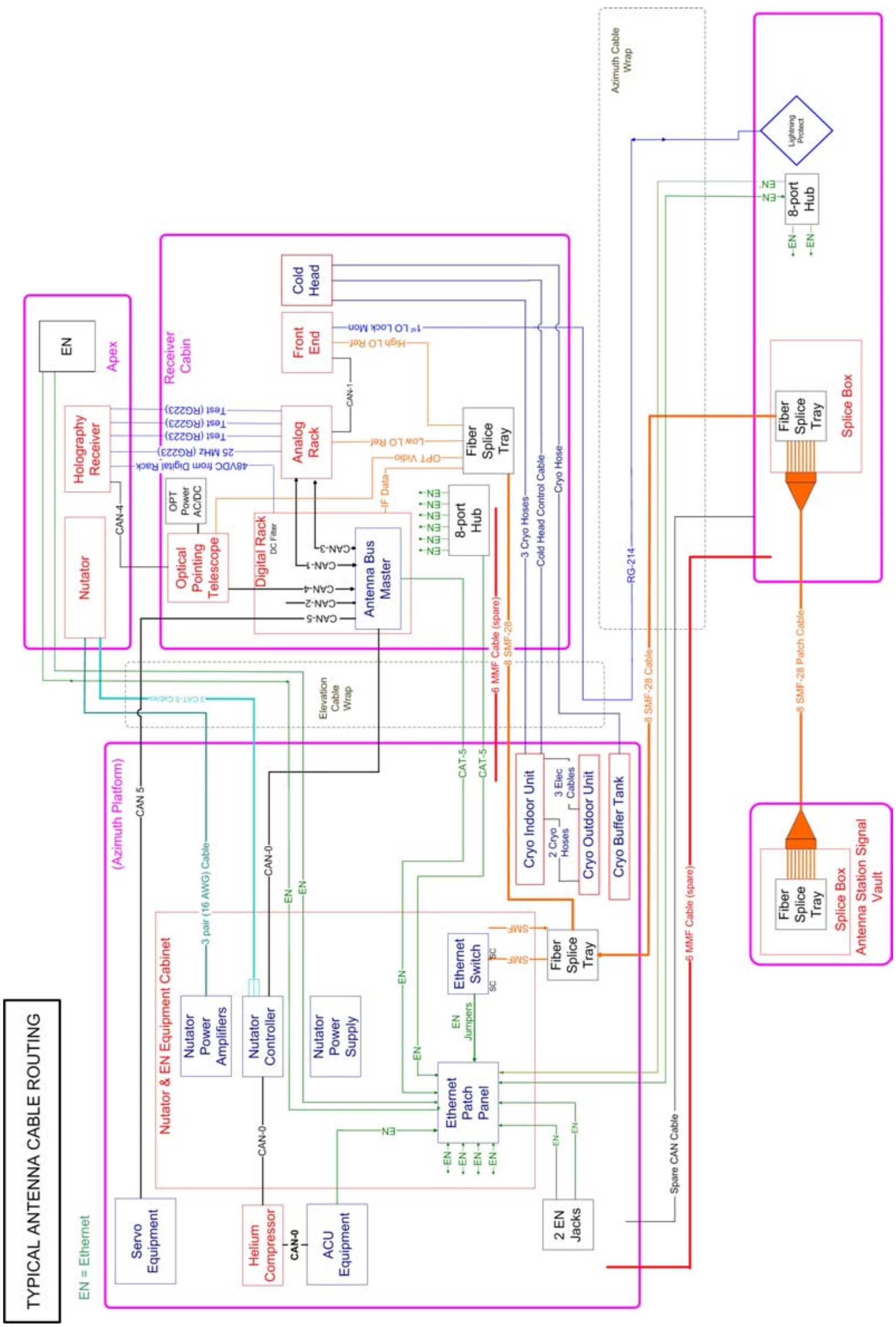


Figure 6.9.2-a ALMA cables (typical)

Cables terminating to the apex shall be routed inside sheathed ducts inside the feed legs.
At least one spare duct inside the legs shall be available for future extensions.

6.9.2.1 CAN-0 Cable requirements

The overall length of the CAN cable (CAN-0 in Figure 6.9.2-a) connecting the ABM, the ACU, the Helium compressor and the Nutator shall not exceed 35m.

6.9.3 ON-AXIS CABLE WRAP

Provisions shall be made for a separate stable fiber optic cable wrap that will pass through the both the azimuth and elevation axes of the telescope. These on-axis cable wraps will hold a fiber optic cable fixed between the stationary and rotating portion of each axes. ALMA will be responsible for providing the stable fiber, as defined in the ICD [05].

The Contractor shall provide accesses in the azimuth and one in the elevation axis for this on-axis special cable wrap. A minimum diameter hole of 40 mm through the center of each axis will be required. This shall include a hole of this size through the azimuth encoder and the elevation encoder if necessary.

Routing of the fiber through the yoke arm shall be possible to avoid routing the fiber through the normal elevation cable wrap. The Contractor shall provide space for a 60 mm conduit to be routed in one yoke arm that is on the same side as the elevation on-axis cable wrap, to contain the thermally stable fiber.

The details required for the on-axis cable wrap are specified in drawing DWG [07]. Details of the stable fiber and required volume for said fiber is contained in ICD [05].

6.10 ANTENNA CONTROL SYSTEM

6.10.1 GENERAL DESCRIPTION

The antenna control system shall be based on a VME bus local controller, the Antenna Control Unit (ACU). The ACU will receive commands from and send status information to the Antenna Bus Master (ABM), a local computer part of the ALMA control system installed in the receiver cabin.

The communication protocol between ACU and ABM is based on the CAN Bus standard link, as specified in AD [6]. The ACU shall not use this CAN BUS link for any other purpose, or to communicate with other devices.

No other communication links are required to the ACU during operation, however a LAN connection to the ACU will be available for integration, commissioning and maintenance purposes.

This control architecture is shown in figure 6.10.1.a.

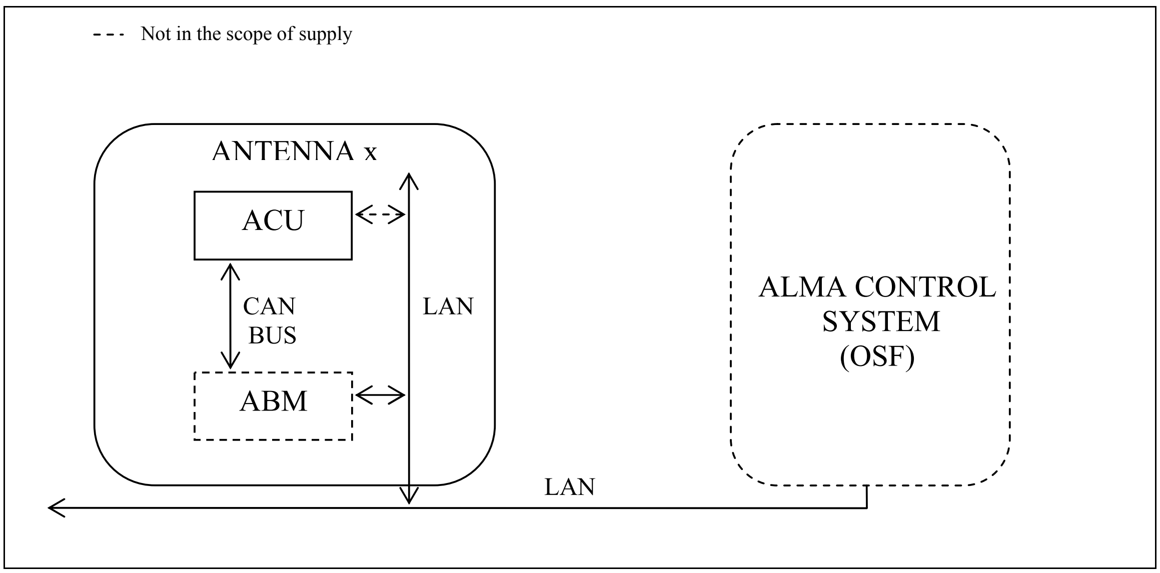


Fig. 6.10.1.a

The ACU shall implement the real time control of all the functions of the antenna. This includes the position servos for the azimuth and elevation axes as well as the control of the subreflector mechanism, the thermal control system, the metrology system and in general the monitoring of the overall status of the antenna.

Beside the ACU, the control system shall contain all the devices: sensors, switches, limit switches needed for the correct, safe and reliable operation of the antenna.

Hardware and Software standards for the ACU are specified in ICD [06].

No components of this system may be located in the receiver cabin except perhaps some low-power sensors, and then only with ALMA's approval. A cable run from any component of this system to the receiver cabin shall not be longer than 18 meters in length.

6.10.2 Local Control and Monitoring

A centralized monitor and control panel shall be provided at each antenna. It shall include at least (1) an Emergency Stop switch (see also 6.10.7.3), (2) selection of Remote or Local access (see 6.10.4), (3) mode selection (see 6.10.4) and (3) rate loop driving of the antenna. It shall display at least the following information:

1. Encoder position (binary and in degrees)
2. Commanded position (binary and degrees)
3. Motor status (each)
4. Field status (each)
5. Motor over temperature (each)
6. Emergency Stop
7. Stow Pins
8. Limit Switch Status (each)
9. Computer Mode Status (each)
10. Each Motor Current
11. Each Tachometer (Pin Jacks)
12. Circuit Breakers (each)
13 Door sensors

6.10.3 Portable Control Unit

A portable control unit shall also be provided for the use of maintenance personnel who may be servicing the antenna. This shall provide at least velocity control loop driving of the antenna in both azimuth and elevation, effective only during Local Access.

It shall be possible to adjust the speed in the range $\leq$ 0.05 deg/sec to 1.0 deg/sec.

The portable control unit shall be equipped with a display providing the encoders reading in degrees.

This portable control unit shall also provide emergency stop control. Provisions shall be made so that the portable control unit can be connected to the antenna base, servo cabinet, and receiver cabin with a removable cable. These cable connections will be waterproof and protected from the weather. The cables shall be made available in both 10 meter and 30 meter lengths.

6.10.4 ACU Modes of Operation

A number of modes of operation are defined for the Antenna Control Unit, The ACU will be at any time in one and only one of the defined operation modes. In addition there are two Access modes to command the ACU, local and remote. In local the antenna will be controlled using the local control panel. In remote it will be controlled via the digital interface.

The complete definition of the ACU operation modes, the rules governing the modes and the transition between them as well as the Access modes to the ACU are defined in ICD [06].

6.10.5 Monitor and Control Digital Interfaces

6.10.5.1 General

The antenna shall be controlled via commands from an ALMA-supplied computer and shall provide status information to the same computer. The connection will be via an ISO11898 CAN BUS whose details are specified in applicable document ICD [06]. The bus may be shared with other devices mounted in the antenna. There are strict timing requirements with respect to the execution of some commands and the sampling of some status data as defined in Section 6.10.5.3.

The primary commands consist of the azimuth and elevation to which the antenna shall be pointed. Other commands may be generally described as changing the mode of operation of the antenna. The details of the commands are defined in ICD [06].

The primary status information consists of the actual azimuth and elevation to which the antenna was pointed at an accurately known time. Additional status information for monitoring the health and safety of the antenna is also required, such as motor currents, temperatures at critical locations, and any detected fault conditions.

Additionally all digital readouts available in the hardware (controllers below the ACU, UPS units etc….) shall be read regularly by the ACU and made available via Status command, to the ABM, to allow remote diagnostics, and to the local control panel.

6.10.5.2 Physical Layer and Low-Level Protocol

The serial data bus is the method by which the Contractor’s equipment will communicate with ALMA's computer via an ISO11898 CAN BUS version 2.0B. Status information will be solicited by polling, and the Contractor’s equipment will not send any messages nor generate any interrupts autonomously.

6.10.5.3 Timing

In addition to a connection to the serial bus, the antenna controller will receive a precise timing reference signal. This will be a periodic pulse, supplied by differential signaling conforming to RS-485. The pulse period shall be 48 ms.

For certain commands, in particular the antenna position command, the antenna controller shall consider the effective time of the command to be that of the second timing event after the command is received. The controller must then ensure that the condition specified by the command becomes true within 10 microseconds of the effective time whenever this is not prevented by a mechanical or structural limit. For other commands, such as mode changes, there is no requirement for precise timing.

The controller shall also measure the actual position of the antenna twice per timing event, with one measurement made within 10 microseconds of a timing event and the other within 1 ms of the midpoint between timing events. Each such measurement shall include the readings of all appropriate sensors (although sensors whose values are known to change slowly may have their readings interpolated from measurements made less frequently). The controller shall store these measurements in a circular buffer sufficient to hold data from at least the last 10 seconds. Status request codes shall be included to solicit (a) the most recent measurement at the last timing event; (b) a subset of the measurements in the buffer (and size shall be negotiated); and (c) all measurements in the buffer. There may be other status request codes that require delivery of a measurement made at the last timing event.

The number of commands and status requests that might be transmitted in a given time interval is limited only by the speed of the bus and its low-level protocol. However, the total number of commands and status requests requiring precise timing will be limited to a maximum of 4 per timing event. The controller shall be capable of processing all of these. Other commands and status requests shall be buffered and executed at lower priority in the order that they were received. The buffer should be capable of storing at least 256 commands and status requests.

6.10.5.4 High Level Command Protocol

Each antenna position command will have 4 parameters, consisting of elevation, azimuth, elevation rate, and azimuth rate. The elevation and azimuth will be 32 bit numbers, interpreted as signed, twos-complement, fixed-point binary numbers representing angles from -1 turn through $+[1-2^{-31}]$ turn (i.e., the binary point comes just after the sign bit). The elevation rate and azimuth rate will be in the same fixed-point format in units of turns per second.

For the elevation parameter, zero represents the horizon and the valid range is from the lower limit (2 degrees) to the upper limit (90 degrees, see 0)). For the azimuth parameter, a value of zero represents the center of the range of rotation (0) and the valid range is from one limit to the other (540 degrees). If out-of-range commands are received, the antenna should be driven to the nearest mechanical limit and an error status bit should be set.

The commanded position and rate apply at the second timing event after the command is received. The ALMA computer will guarantee that the command is available no later than 10 ms in advance of the next timing event. If no position command is received between two timing events, the position and rate applicable at the next timing event shall be derived by constant-velocity extrapolation of the most recently received command. In this way, there is a commanded position and rate that applies at each timing event. At any time between timing events, the commanded trajectory shall be determined by a fixed interpolation rule chosen by the Contractor to produce smooth motion, taking into account the response of the servo. The position and velocity command is the primary control interface.

The servo shall attempt to make the actual trajectory of the antenna follow the commanded trajectory. If the latter contains first or second derivatives exceeding the maximum angular velocity or acceleration (see 5.2.1), the servo shall drive the antenna so as to converge to the commanded trajectory as quickly as possible while meeting the settling time requirements of Section 5.4.4.

The antenna may have several sub-modes of active operation determined by the Contractor, but at least the following two modes shall be included.

<u>Autonomous pointing mode:</u>

In this mode, position commands are interpreted to mean the actual orientation of the axis of symmetry of the main reflector *(boresight axis)* with respect to established local coordinates (zenith direction and nominal azimuth zero). The controller shall determine this automatically by using all available sensors and, if necessary, calibration information specific to this antenna that has been previously determined and stored. Accuracy specifications given in Section 5.3 are expected to be met.

<u>Encoder positioning mode:</u>

In this mode, position commands are interpreted to mean the readings of the azimuth and elevation shaft rotation sensors (encoders). The readings of other sensors shall be ignored in executing the position command, but they shall still be measured and recorded for reporting in response to status requests.

6.10.6 COMPUTING AND SOFTWARE

It is assumed that the Antenna Control Unit will be based on one or more microprocessors embedded in one VME rack. The operating system of the microprocessor(s) used shall be RTAI real-time Linux. Below the ACU level commercial controllers can be used, provided they do not require any specific software to be developed.

The source code for the ACU processor(s) is a deliverable item as well as the software test procedures.

It is required that (a) all application programming for processors in the ACU be written in C or C++; (b) executable code be stored in non-volatile electronic memory, avoiding mechanically driven peripherals such as disk drives.

All RTAI microprocessor systems shall have Ethernet interfaces for debugging and testing.

There shall be procedures (part of the deliverable SW) to allow source code modifications to be made, compiled and loaded into the non volatile memory of the ACU, remotely.

6.10.7 INTERLOCKS

An interlock system shall be implemented in the Antenna to avoid hazardous situations and to allow safe maintenance operations (AD [6]

Each interlock source shall provide a pair of potential-free contacts and its status shall be monitored, but not controlled, by the ACU.

All the interlock source contacts shall be series connected to form an interlock chain controlling the power supply to the interlocked subsystem and the brakes (if any) associated to that subsystem.

6.10.7.1 Transporter interlocks

In order to allow safe transport operation and to avoid any simultaneous movement of the Antenna and the Transporter, the following interlock strategy shall be implemented:

- A selective interlock shall be activated when the Antenna is powered from the transporter to inhibit all the moving functions (Elevation, Subreflector) except the Azimuth axis. Under this condition it shall be still possible to move the Azimuth axis by means of the PCU.
- The Antenna interlock chain shall accept a potential-free pair of contacts coming from the Transporter, so that the Transporter can interlock the whole Antenna (including the Azimuth axis) opening the contacts when the Antenna is powered from the transporter.
- The Antenna interlock chain shall provide a potential-free pair of contacts to interlock the Transporter, opening the contacts while the whole Antenna is not interlocked.

6.10.7.2 Limit Switches

There shall be two limit switches near each extreme of motion of each axis, at slightly different positions: the Pre-limit and the Final Limit.

The two switches shall use independent wiring and independent circuit components as much as possible; the likelihood of a component failure affecting both circuits shall be minimized.

6.10.7.2.1 Pre-limit Switch

When the Pre-limit switch is actuated, the controller shall inhibit driving further in the same direction (into the limit), but should permit driving in the opposite direction (out of the limit) in all modes. In this condition receipt of a command (Remote or Local) that would cause motion into the limit shall cause the controller to enter Shutdown Mode, and thus to remove motor power and engage the brakes. An override switch shall be provided to disable these features of the Pre-limit switch. This switch shall be accessible only locally (not via remote control), and it shall not be on the control unit's front panel (AD [6]).

The action of the Pre-limit switch is not properly an interlock, being handled by the ACU.

6.10.7.2.2 Final Limit Switch

When the Final Limit switch is actuated, all motion of the antenna shall be stopped by causing the controller to enter Shutdown Mode immediately. In addition, each Final Limit switch shall include a set of normally closed contacts through which at least one brake of its axis must be operated. There shall be no provision in the ACU for overriding the Final Limit switches. The Contractor shall include provisions for manual override of brakes and axis drives.

The Final Limit Switch acts on the corresponding axis drive system as a selective interlock, cutting the power to the corresponding drive.

6.10.7.3 Emergency Stops

Several Emergency stop pushbuttons shall be integrated in the Antenna interlock system. The setting of an emergency stop switch shall completely remove power from all the motor drives and cause the brakes to be engaged. It shall cause the control system to enter the Shutdown mode, but the removal of motor power and engaging of brakes shall be independent of any other control circuits; it shall be effective even if the main electronics chassis is not working or powered down. These switches are to be located in at least the following locations:

1. In the receiver cabin
2. Two on the antenna base
3. One on each set of elevation drive motors
4. One on each azimuth drive motor
5. At the local control front panel
6. On the Portable Control Unit (PCU)

These switches shall be equipped with labels

While the antenna is in motion stop, a continuous green light shall be activated. (see Section 7.3.)

6.10.7.4 Local disable

A selective local disable function of the main axes and of the subreflector shall be available for maintenance purposes. It shall be based on a switch that cuts the power to the drive and at the same time interlocks the corresponding subsystem causing the brakes to be engaged.

6.10.7.5 Lock-out/Tag-out

In order to assure Personnel safety during maintenance operations, a Tag-out/Lock-out function shall be provided as demanded by AD [6] that cuts the power to all the moving parts (Azimuth axis, Elevation axis and subreflector).

It shall be a separate section of the interlock system, having an independent energy isolating device, or circuit breaker, which can be padlocked in safe (power off) position for Lock-out/Tag-out.

6.10.8 FAULT CONDITIONS

The control system shall continuously monitor fault conditions that may affect the safety of equipment or personnel, and shall automatically enter Shutdown mode if a serious fault is detected. Serious faults include, but are not limited to:

1. Excessive motor current
2. Motor overheating
3. Large Servo oscillation/ instability
5. Critical sensor fault (especially an encoder) or power failure
6. Overspeed of the azimuth or elevation axis.

The overspeed monitoring system shall be independent of the main axes encoders. Any error condition that may cause overspeed shall not have the potential of also leading to a malfunction of the overspeed monitoring system.

Other fault condition, not linked to safety, but affecting proper operation of the antenna shall also be monitored (Shutter, stow pins, etc) .

6.10.8.1 Automatic Survival Stow Conditions

The antenna will automatically enter survival stow mode under the following conditions:

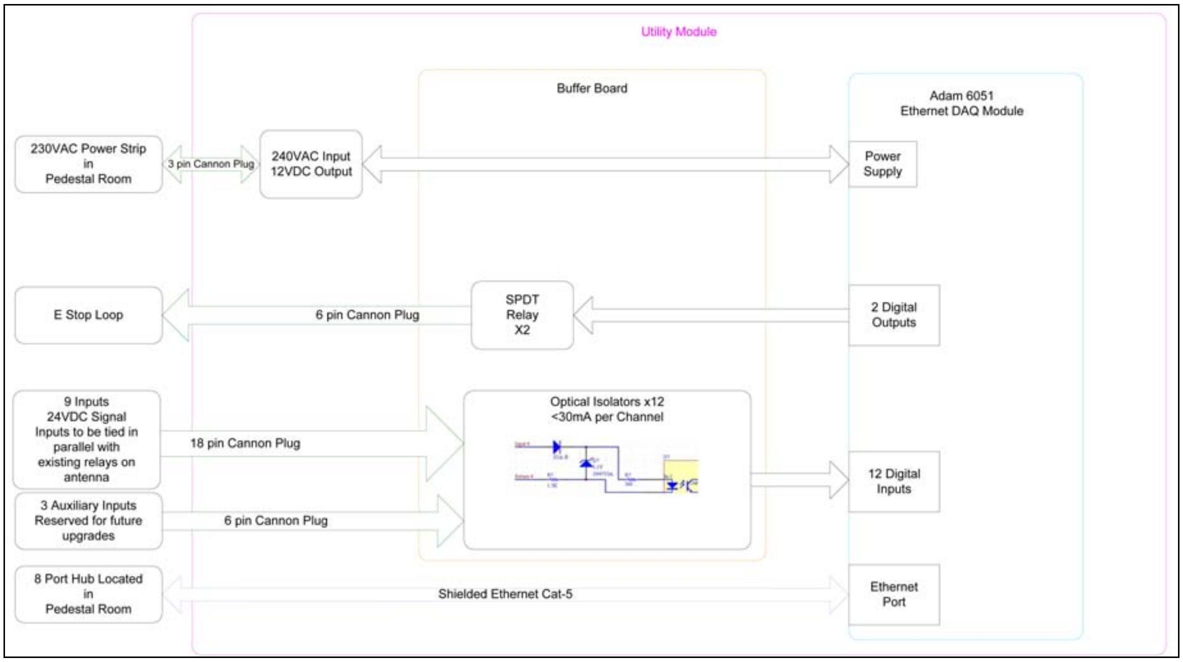
ACU Commanded

No commands or time signals received for a time settable from 1 minute to 60 minutes when in remote access.

6.10.9 UTILITY MODULE

The Utility module shall receive the alarm conditions specified for the utility module in ICD [06] and relay this information via its own IP address on Ethernet.

The Utility Module shall have software and hardware interfaces equivalent to the *ADAM-6051, Data Acquisition Module, available from B&B Electronics,* and be provided, mounted and fully tested on the antenna by the Contractor, who should also prepare and deliver test software to fully exercise and demonstrate the Utility Module functionality during the Antenna acceptance phase. The functions of the Utility Module are described in [ICD 06].



6.10.10 SPACE REQUIREMENTS

The Contractor shall allocate the necessary space to accommodate the various equipment foreseen by the ICD (switches, cables, ABM etc,)

6.11 METROLOGY

For the purpose of achieving the pointing specification (Section 5.3) and the path length error specification (Section 5.6) the contractor shall provide a metrology system able to estimate as a minimum:

Tilts in the structure of the antenna (base, yoke) after or between relocation

Temperature measurement and thermal deformation of the structure

Wind structural deformation

Additional equipment hardware and software that is necessary to achieve the specification shall be provided together with the real time correction software in the ACU computer.

All data provided by all of the metrology equipment mentioned above in this section will be provided as digital monitor data from the dedicated metrology computer to the ALMA Antenna Computer. All metrology equipment will be monitored and controlled by the Contractor’s equipment.

The metrology algorithms shall be described in the documentation.

6.12 ELECTRICAL REQUIREMENTS

6.12.1 POWER DISTRIBUTION

The antenna electrical installations shall conform to AD [11] (IEC 60364, all 'Parts' as applicable). The antenna shall be suitable to be operated at 230/400 VAC (230V being the phase-to-neutral and 400 V the phase-to-phase voltage), 50 Hz (rated frequency at the ALMA Sites).

Electric power shall be distributed within the antenna by means of five distinct conductors insulated from each other, namely L1, L2, L3, N and PE (US: equipment grounding conductor). Therefore the neutral conductor N shall be kept insulated from the protective conductor PE as well as from any other conductors of the earthing system (earth electrodes, earthing conductors, equipotential conductors, exposed and extraneous conductive parts, etc.).

When mounted onto an antenna station, the antenna electrical installations shall conform to what specified by AD [11] for TN-S systems.

The antenna shall also be able to be supplied and operated with the AC electric power provided by the antenna transporter. The antenna transporter, with and without the antenna connected to it, will constitute a 'mobile unit' conforming to AD [11] (IEC 60364; in particular, but not exclusively, IEC 60364 'Part 7-717: Requirements for special installations or locations – Mobile or transportable units'). As far as its electrical installations are concerned, the antenna (and the antenna transporter) shall conform to the applicable requirements of AD [11] also when being connected to or placed onto the antenna transporter (in particular but not exclusively, to IEC 60364 'Part 7-717: Requirements for special installations or locations – Mobile or transportable units' and to IEC 60364 'Part 5-55: Selection and erection of electrical equipment – Other equipment'). It is pointed out that during transportation the transporter and the antenna located onto it shall constitute a mobile unit without an earth electrode, as defined in IEC 60364-7-717.

The Contractor shall provide a 75 kVA electrical service entrance at the base of the antenna for connection to the ALMA Power Distribution Systems.

The value of 75 kVA shall constitute the peak apparent power that the antenna is allowed to demand, including the demand of the antenna UPS input at rated load while boost charging the UPS battery.

Not more than 55 kVA shall be demanded by the antenna contractor equipment, including (but not limited to):

- the demand of the antenna UPS input at rated load while boost charging the UPS battery
- the peak power demand from both axis drives over the most onerous fast motion (most likely the fast switching phase calibration under secondary operating conditions)

but excluding

- the power demand from the cryo compressor.

The antenna design report(s) shall include calculation and representation of the most onerous power demand waveforms.

The electrical service entrance shall encompass a manually operated switch that shall be located at the base of the antenna to allow the selection of one of the two AC power sources of the antenna, i.e. the ALMA power system or the transporter, one at the time. The position of the manually operated switch shall be monitored by the ACU and the information made available to the ABM and to the local panel. The first power input (from the ALMA Power Distribution System, that is, the AC power in the antenna stations) shall be via a plug as described in ICD [02]. The second power input (from the AC power generated on board of the antenna transporter) shall be via an appliance inlet as described in ICD [03]. The service entrance shall encompass the above-mentioned plug and appliance inlet, including the relevant power wiring, electrical interlock wiring, etc. The Contractor shall be responsible for all his/her antenna electrical wiring from the interfaces described above, that is, from the plug and from the appliance inlet included. The manually operated switch shall prevent the generating set installed on board of the antenna transporter from operating in parallel with the ALMA Power Distribution System. For what not specified here, this switch shall conform to what required by AD [11] (in particular, but not exclusively, with IEC 60364 'Part 5-55: Selection and erection of electrical equipment – Other equipment' and IEC 60364 'Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control').

This double power input shall allow the antenna to be supplied by the ALMA Power Distribution System as well as by the transporter AC power during transportation and removal from/placement on an antenna station. 230 VAC phase-to-neutral and 400 VAC phase-to-phase voltages at a frequency of 50 Hz will be provided to the antenna at both its power inputs via five distinct conductors (L1, L2, L3, N and PE).

During transportation the antenna plug shall be mated with a dummy socket-outlet that shall be incorporated in, or fixed to, the antenna for this purpose. When mated, the antenna plug and this dummy socket-outlet shall exhibit the same degree of protection (according to IEC 60529 or NEMA 250) specified in ICD [02] for the plug when mated with the antenna station socket-outlet. Plugs, socket-outlets (US: receptacles), appliance inlets, connectors and similar accessories shall conform to AD [4].

For what not explicitly specified by AD [11] and by the present section '6.12 Electrical Requirements', all electrical installations shall conform to AD [6].

The antenna Contractor shall supply a three bus AC power system as defined in the following.

The first bus shall be the "Critical Electronics Bus" for receiver cabin electronics, encoding systems, ACU and safety systems with a sub-panel in the receiver cabin. The power for this bus shall be supplied by a 15 kVA (at elevation 5000 meters) UPS system. This UPS system shall not be located in the receiver cabin but at a location on the antenna (to be transported with the antenna) chosen by the Contractor.

The second bus shall be the "Critical Cryogenic Bus" that shall power the helium compressor and the cryogenic refrigerator.

The third bus shall be the "Non-Critical Bus" for lighting, HVAC, with sub-panels in the receiver cabin and base of telescope. The bus system is also listed in the Table 6.12.1-1.

Bus	Systems on Bus	UPS
(1) Critical Electronics Bus	Receiver cabin electronics, encoding systems, ACU, safety systems	UPS System (15 kVA) for a minimum of 10 minutes, 230/400 VAC
(2) Critical Cryogenic Bus	Helium compressor & cryogenic refrigerator	No UPS
(3) Non-Critical Bus	All other system, including prime drives & HVAC systems	No UPS

Table 6.12.1-1 - Bus Power Distribution

Size and type of the circuit breakers that will supply equipment installed by ALMA will be determined later by ALMA. Fuses shall not be used for equipment protection. All three buses shall have single phase and reverse phase protection interlocked with smoke detectors specified in section 8.3.4.1.

The drive system prime power shall be connected to a 3-phase circuit breaker located on the antenna pedestal. The connections from this circuit breaker to the motor amplifiers shall be by wire and conduit.

Electronic components of the system shall be connected to 230 VAC, single-phase, 50 Hz and be protected by surge protective devices (SPDs). The encoder prime power shall be connected to the same source and have surge protection. This prime power shall be connected to a disconnecting device (supplied under this contract) that will allow resetting all servo and encoder power supplies, motor faults and other faults. The disconnecting device will be actuated by an ALMA-supplied remote 28 Volt DC signal. More on surge protection can be found in section 6.12.3.

Instantaneous tripping currents of overcurrent operated circuit breakers shall be so selected as to avoid false operation due to large inrush currents. Miniature circuit-breakers (MCBs) shall have time-current characteristic "K".

6.12.2 JUNCTION BOXES

Junction boxes shall be provided to accommodate all electrical connections to be supplied by the Contractor. Separation in junction boxes shall be provided for power and signal wiring; junction boxes shall be Type IV according to NEMA 250 'Enclosures for Electrical Equipment' or IP66 according to IEC 60529 'Degrees of protection provided by enclosures (IP Code)'.

6.12.3 GROUNDING, PROTECTION AGAINST LIGHTNING AND LEMP

The antenna requires safety and equipment grounds. An antenna station grounding (earth) electrode will be provided for each antenna station. ALMA will provide the antenna station grounding (earth) electrode as a part of the foundation construction. The apex, elevation bearings and azimuth bearing shall have by-pass grounding connections. The antenna grounding system shall be specifically designed to prevent or minimize ground loops.

The antenna shall be provided with a lightning protection system conforming to AD [21] "IEC 61024 - Protection of structures against lightning":

- Part 1: General principles;
- Part 1-2: General principles - Guide B - Design, installation, maintenance and inspection of lightning protection systems.

To determine the zone of protection (zone not subject to direct lightning strokes - LPZ 0_B) the rolling sphere model shall be adopted.

The lightning protection system shall be designed to achieve Protection Level I as defined by AD [21] "IEC 61024-1".

The earth termination system (ground terminal) will comprise a ring earth electrode (bonded to or constituted by a foundation earth electrode in form of a loop), supplemented by additional radial electrodes where required by AD [21].

Members of the external lightning protection system (air-terminations, down-conductors, earth-termination system) shall be chosen by adopting, as far as practicable, "natural" components (that is, components that perform a lightning protection function but that are not installed specifically for that purpose).

Equipment installed onto the antenna as well as cables, wiring and any lines interconnecting them (thereby including any metallic pipes) shall be provided with protection against overvoltages and against lightning electromagnetic pulse (LEMP) conforming to AD [22] (IEC 61312-1, IEC TS 61312-2 and IEC TS 61312-3). To this purpose the Contractor shall assess which are the lightning protection zones - LPZs - around and within the antenna structure.

Structural bonding shall be adopted in order to obtain from "natural" components - as far as possible - the protection and the shielding measures required by the lightning protection zones 0_B and higher.

For each piece of equipment to be installed and for each conductive part to be laid (including cables of any types and for any applications, metallic pipes, etc.), the Contractor shall choose which is the appropriate lightning protection zone. Upon need, the Contractor shall conveniently design or re-design dimensions, form and borders of the lightning protection zone of the requested level.

As far as possible, conductive parts (i.e., cables of any types and for any applications, metallic pipes, etc.) within a given lightning protection zone (e.g., LPZ 0_B) shall enter into an inner lightning protection zone (e.g., LPZ 1) at a single point of entry. At this point the conductive parts shall be bonded to the boundary (shield) between the outer and the inner

LPZ. Conductive parts not carrying operating currents/voltages - and, therefore, including protective conductors (equipment grounding conductors), metal conduit, armours, sheaths, shields, etc. - shall be bonded directly to the boundary (shield).

Live conductors of any circuits (power, data, signal, communication, control, etc., thereby including the neutral conductor N of power circuits) shall be bonded to the boundary by means of surge protective devices – SPDs (surge arresters).

SPDs shall be chosen, arranged and coordinated at the LPZ interfaces (transitions from one LPZ to another) in conformity with what specified by the 'Part 3: Requirements of surge protective devices' of AD [22].

Live conductors to be connected to equipment particularly susceptible to overvoltages shall be bonded to the LPZ boundary by means of a chain of SPDs (e.g., a gas discharge tube, a varistor and a zener diode with inductors as decoupling elements).

6.12.4 SINGLE-PHASE AND REVERSE PHASE PROTECTION

Single phase and reverse phase protection shall be provided and shall be interlocked to remove all electric power on the antenna. When a single phase or reverse phase problem is detected the detector shall immediately close a contact which will be used by ALMA for a remote alarm. The shunt trip of all power shall occur 5 seconds after detection of the problem. This shunt trip shall automatically reset after proper conditions are restored. Emergency power for the single phase and reverse phase detectors shall utilize "Gel-cells" with a minimal reserve of 6 hours. All electrical and electronic wires shall be in metal conduits unless specifically approved by ALMA.

7 INTEGRATION, SERVICE, TRANSPORT AND TESTING

7.1 RECEIVER CABIN EQUIPMENT HANDLING

Maintenance and exchange of receivers will occur frequently on the antennas. Receivers will be handled on manually propelled wheeled carriages (receiver trolley) with an integrated lifting system for lifting the receiver inside the cabin from the floor to the receiver flange.

A dedicated receiver service vehicle will drive to the antennas for bringing and taking away receivers. The receiver service vehicle will be equipped with a lifting system to lift up the receiver trolley and personnel to the level of the receiver cabin floor.

A receiver installation platform shall be installed on the antenna outside of the receiver cabin, where the vehicle mounted lifting system can be docked and the trolley can roll from the floor of the lifting system over the receiver installation platform into the receiver cabin.

Requirements for the receiver cabin installation platform are given in applicable drawing DWG [03].

To achieve a safe transfer from the vehicle mounted lifting system to the antenna mounted platform the lifting system will press against the platform horizontally and vertically with forces defined in DWG [03].

The receiver installation platform shall be equipped with railings and footboards to secure personnel and the receiver trolley. The front railing section shall open like a gate for the transfer of the receiver trolley. Opening of the gate shall be possible from both sides, the platform side and from the side of the lifting system. The open gate shall be detected by the ACU.

An alternative access and escape way to and from the receiver installation platform shall be provided by a ladder, staircase or similar mounted on the antenna.

During receiver handling, before the receiver service vehicle approaches the antenna, the antenna axes movements shall be locked out safely. The locked out status shall be visible for the driver of the service vehicle before he enters into the dangerous zone.

7.2 ACCESSIBILITY

7.2.1 ACCESS PLATFORM

Antenna mounted ladder and/or platforms shall be provided to allow personnel access to the receiver cabin while the antenna is in maintenance stow position.

In addition to the receiver installation platform in section 7.1 access platform shall be provided for all contractor and ALMA equipment that can not be located in other areas of the antenna and require some level of human interface. Examples of this equipment include ALMA cryogenics equipment, local control panels, ACU cabinet, etc.

7.2.2 ACCESS AND MANHOLES

Convenient access for maintenance operation shall be provided to all equipment located inside the base and the yoke. If doors cannot be used, manholes of adequate size shall be provided.

Covers and hatches to the manholes shall consider ergonomic design principles and generally require only human force for opening and closing. Where equipment to be serviced and LRUs are located, a fast opening methods shall be foreseen, also taking into account the possible presence of insulation panels. The opening in the structure at the manhole shall be reinforced if necessary in order to avoid bolted doors.

Careful access and ergonomic consideration shall be given to the location and mounting of all equipment which must be accesses via manholes for maintenance.

Enclosed spaces (example: yoke structure) where personnel is required to perform inspection or maintenance activities shall be equipped with lights. Procedures related to manholes and enclosed spaces shall be established and covered in the maintenance manual.

7.2.3 ACCESS LADDER /STAIRS

Access ladders and/or stairs shall be provided for personnel to access the access platform and receiver installation platform from the ground level. All ladders and stairs shall comply with the volumes specified in section 4.3.3 and 4.3.4 of this specification. Ladders and stairs shall also comply with safety standards, including AD [12].

As a general rule position switches shall be included in the design of all movable or removable ladders, stairs and railings which may be safety relevant. The implementation shall follow the rules of Section 6.10.7.

The access ladder shall be caged and lockable in order to prevent unauthorized access.

7.3 CLOSE PACKING PARKING

The close packing parking position will be remotely commanded by ALMA, because it is station dependent in Azimuth. The antenna will be parked in the position remotely. The operator will operate the motion stop. The motion stop shall provide power to a continuous green signal lamp located in a position visible from the antenna transporter and signaling the safe passage of the loaded transporter.

7.4 SERVICE AND TESTING EQUIPMENT

7.4.1 COUNTERWEIGHT FOR BALANCING

It shall be possible to adjust the counterweight of the elevation structure according to the different mass of the ALMA instruments (Front End and Back End equipment, holography receiver, cabling etc) installed.
The following applies:

- Total range of adjustment +/-12000 Nm
- Minimum adjustment step 300 Nm

It shall be possible to modify the balancing of the elevation axis of 1500 Nm in maximum 1 hour work for two personnel, including the possible removal of cabin floor covers, insulation etc, as demanded by the specific design adopted.

7.4.2 SERVICE EQUIPMENT

Service equipment shall be constituted by all handling, diagnostics and maintenance tools, necessary for ALMA to maintain the Antennas after delivery. This does not include standard access equipment, cranes, transport trailers, but includes:

- Hoisting equipment and fixtures to lift, mount and remove LRUs
- Subreflector handling tool, including protective cover
- Panel setting tools, manual and automatic
- Specifically designed diagnostic tools
- Servicing tools
- Calibration tools
- Transport / storage boxes *(if applicable)*
- Additional tools, not specifically mentioned here but foreseen by the Maintenance Manual.

As a general rule ALMA shall be able, after delivery of the tools, to perform all planned maintenance activities on the antenna, corrective maintenance at the level of LRU's exchange and planned overhaul.

7.4.2.1 Panel Setting Tools

It shall be possible to adjust the panel setting by using manual tools as well as automatic tools. Two type of tools shall be provided:

- Manual tools. This type of tools shall be essentially non automatic, and be provided with a graduated scale to be read in micrometers in order to set the panel position.
- Automatic tools. This type of tools shall be able to identify each panel adjuster position individually. Upon identification of the panel adjuster it shall be possible to perform the adjuster setting in automatic mode to a value previously stored in the tool.

A procedure to download all values for a full surface shall be provided with the tool. Corresponding provisions for the identification of the adjusters shall be included in the adjuster.

7.4.3 OPTICAL TELESCOPE FOR POINTING TEST

An optical telescope will be mounted on the antenna for pointing tests that will be used to test the mount of the antennas. The design and Interface requirements for the Optical pointing telescope are defined in DWG [05].

This telescope will be mounted on the antenna BUS in a stable position in order to represent correctly the pointing of the antenna as given by the axes drives. Light will be collected through a suitable hole the reflector surface.

A rim will be put on the panel around the hole to prevent large entrance of water. ALMA will provide the optical telescope and install the unit.

The Antenna shall be equipped with a stable mount on the BUS for the optical telescope and a cut-out through the reflector surface for the telescope to protrude.

The attachment point of the Optical pointing telescope shall have a rigidity such to ensure a maximum differential deflection of the telescope over the elevation range of the antenna not exceeding 0.2 arcsec. It shall be furthermore mounted in a thermally stable environment. (Tests will be performed during nighttime)

7.4.4 HOLOGRAPHY RECEIVER

The Holography Receiver provided by ALMA will be used to set the main reflector surface to the final accuracy specified in section 5.4. The requirements for the interface from the Antenna to the Holography Receiver are contained in ICD [07].

8 RELIABILITY/MAINTAINABILITY/SAFETY REQUIREMENTS

8.1 LIFETIME AND RELIABILITY REQUIREMENTS

The antennas shall be designed for a minimum lifetime of 30 years considering 24 hours per day of operations and considering the environmental conditions specified in AD [2].

For the computation of the lifetime, the reliability, the failure rate and the maintenance it shall be assumed that each antenna will execute during its lifetime:

- Not less than 270,000 complete cycles of elevation motion, where a complete cycle of elevation motion is here defined to be movement of the reflector from its lower elevation limit up to its upper elevation limit and back down to its lower elevation limit.
- Not less than 200,000,000 degrees of total motion about each axis.

At least 50 million of fast switching cycles during its lifetime.

At least 2 million cycles of focus switching mode of the subreflector mechanism

- At least 20 million steps of focus adjustment for the subreflector mechanism.
- At least 20 million steps of collimation steps for the subreflector mechanism.

The Mean Time Between Failure (MTBF) of the antenna operated under the operational conditions specified in Section 4.4 shall not be less than 3 years.

A Failure is defined as a loss of operation of the antenna implying at least one of the following cases:

- The antenna needs to be brought to the OSF for corrective maintenance.
- The antenna is not able to move on one axis, and the operability is not recoverable with a corrective maintenance intervention of 2 hours and two people. (Travel time from the OSF not included)
- The antenna has a degraded pointing performance and it is not able to point better than 5 arcsec absolute pointing or 2 arcsec offset.
- A failure of the HVAC such that the temperature in the cabin cannot be controlled better than +/- 1.5 degrees.
- Failure to operate the subreflector mechanism.
- UPS failure

8.2 MAINTAINABILITY

8.2.1 REQUIREMENTS LINKED TO ALTITUDE

The design of the antenna shall take into consideration that the antenna will be installed, relocated, operated, and to the possible extent, maintained, at the Array Operation Site located at 5000m above sea level.

All corrective and preventive maintenance operations shall take into account Human Factors Engineering criteria. In addition the ergonomic force limits to be applied for in the maintenance procedures to be performed at the AOS shall not exceed 70% of the limits at sea level.

8.2.2 MAINTENANCE APPROACH

The maintenance tasks shall be minimized and to the extent of possible be limited to preventive maintenance tasks.

Maintenance shall be mainly performed at assembly and subassembly level by exchange of Line Replaceable Units (LRU's). LRU's are defined as units which can be easily exchanged (without extensive calibration, of sufficient low mass and dimension for easiness of handling, etc.) by maintenance staff of technician level. LRU exchange shall be performed at the AOS site.

LRU exchange shall be possible by 2 trained people within 4 working hours on the installed antenna. As support equipment one manlift for 2 persons and one truck mounted light crane will be available, as well as standard tools and special tools delivered within the scope of the antenna contract.

A step by step procedure for safe exchange of every LRU shall be provided.

The following equipment shall be considered as a LRU as a minimum:

- Subreflector
- Subreflector mechanism
- Feed shutter
- Elevation encoder(s)
- Azimuth encoder
- Electronic cards and drives
- Helium compressor (to be taken into account for access)
- Stow pin assemblies
- End stops
- Elevation cable wrap parts (excluding cables and cable installation)
- HVAC system components
- Components of the UPS
- Locking pins

- Lightning arrestors (1 unit)
- Temperature sensors (1 unit)
- Tilt meters.

Others LRU shall be defined by the Contractor, depending on his design.

The LRU's are maintained by the ALMA project (with or without industrial support).

8.2.3 PREVENTIVE MAINTENANCE

Three kind of maintenance are to be considered in this category:

Periodic preventive maintenance

Overhaul

Alignment of the reflector

8.2.3.1 Periodic Preventive Maintenance

This maintenance is the planned interval maintenance which is performed at the AOS site in order to maintain the antenna operational and within its specified performance. This includes checking, greasing, substitution of consumables, visual inspection, etc.

All maintenance operation shall be planned in the Programmed Check and Intervention List (PCIL) of the Maintenance Manual, which shall list the tools, the procedures and the time necessary for their execution and their periodicity.

It shall be possible to perform these maintenance activities with the antenna stowed in the "maintenance stow" position as defined in Section 4.4.5.

The normal preventive maintenance shall not exceed 4 working-hours for 2 persons every 3 month on each antenna.

Any greasing operation or lubrication activity, which needs to be performed at interval shorter than 2 years should be automatic.

8.2.3.2 Overhaul

Overhaul is a planned major maintenance operation which is performed at the OSF site. The following applies:

No overhaul operation shall last longer than 3 weeks.

No overhaul operation shall be required at interval shorter than 10 years.

Periodical painting and surface protection shall not be necessary more often than every 10 years and shall be planned at the time of overhaul.

Overhaul activities, including painting and possible exchange of Azimuth and Elevation bearings, shall be described in the Maintenance Manual

8.2.3.3 Alignment of the Primary Reflector

ALMA will realign the reflector panel when the RMS surface accuracy has degraded more than the total ageing components considered by the Contractor for his error budget (Backup Structure, adjusters and reflector panels). This should not be necessary at interval shorter than 5 years. This operation is planned to be performed at the AOS site.

A full primary reflector surface adjustment should require no more than 6 hours of work for two people, with the use of a cherry picker and the antenna in the stow survival position.

The Contractor shall implement an automatic system recognizing each adjuster position, and an automatic tool to set the adjuster position to a preprogrammed value. The preprogrammed values shall be provided by ALMA, on the basis of Holographic measures and downloaded to the tool.

8.2.3.4 On-Site Repair / Corrective Maintenance

Replacement or repair takes place only in case of failure of an item. On site repair is normally limited to the in-situ exchange of LRUs.

Repair activities and corrective maintenance shall not demand more than 4 hours per month for two trained technicians.

8.2.3.5 Monitoring Points and Test Routines

8.2.3.5.1 Monitor points

The status of antenna variables which may be relevant for assessing life degradation and antenna troubleshooting (example motor and transformer temperatures, overshoots, lubrication levels etc…) shall be available for monitoring and treatment by ALMA, even if not specifically defined by the ICD [06]. The contractor shall define these variables according to his design, and include them in the updated version of the ICD.

8.2.3.5.2 Self test

Self test shall be executed on switch-on or at other times at ALMA request in order to locate failures down to LRU level. Self test shall:

- exercise functions
- check initialization procedure
- Carry out test at ACU level

It shall be possible to initiate the self test routine in remote mode and from the local control panel.

The Contractor shall define suitable command(s) to execute the self test and report status. This shall be reflected in the updated ICD [06].

8.3 SAFETY

8.3.1 GENERAL

In order to achieve protection against all possible hazards, the antenna shall be considered as a piece of machinery and its design and construction shall comply with the requirements set forth in this section (8.3). A Hazard Analysis shall be prepared according to section 8.3.2. A Safety Compliance Assessment shall document all information on all safety related issues relevant to the system. For the contents of such report see section 8.3.3.

8.3.2 HAZARD ANALYSIS

8.3.2.1 Hazard Severity

Hazard severity categories are defined to provide a qualitative measure of the mishap.

Category	Description	Definition
I	CATASTROPHIC	Death or system loss[1)]
II	CRITICAL	Severe injury, major occupational illness, major system damage[2)]
III	MARGINAL	Minor injury, minor occupational illness, minor system damage[3)]
IV	NEGLIGIBLE	Less than minor injury/occupational illness and minor system damage

1) System loss: the antenna and/ or the Front End system cannot be recovered at reasonable costs
2) Major system damage: the antenna and /or the Front End systems can be recovered but extensive industrial support is necessary and/or the system is out of operation for more than 3 weeks
3) Minor system damage: the antenna and/or the Front End systems can be repaired by ALMA without any support from industry and/or the system is less than 3 weeks out of operation.

Table 8.3.2-1 - Hazard Severity Categories

8.3.2.2 Hazard Probability

Classification of the probability of hazards occurring during the 30 years of expected lifetime of the Antenna is defined in the following table:

Level	Definition	Description
A	FREQUENT	Likely to occur frequently. (typically once a year)
B	PROBABLE	Will occur several times. (6 to 10 times in 30 years)
C	OCCASIONAL	Likely to occur. (2 to 5 times in 30 years)
D	REMOTE	Unlikely but possible to occur. (typically once in 30 years)
E	IMPROBABLE	So unlikely that the occurrence can be assumed not to be experienced (>>30 years)

Table 8.3.2-2 - Probability levels

8.3.2.3 Hazard Risk Acceptability Matrix

The following two matrices define the degree of acceptability of the various hazard categories:

Frequency of Occurrence	I Catastrophic	II Critical	III Marginal	IV Negligible
FREQUENT	I A	II A	III A	IV A
PROBABLE	I B	II B	III B	IV B
OCCASIONAL	I C	II C	III C	IV C
REMOTE	I D	II D	III D	IV D
IMPROBABLE	I E	II E	III E	IV E

Table 8.3.2-3 - Hazard classification matrix

Hazard risk index	Assessment criteria
I A to I D, II A, B; III A	Unacceptable
II C, D; III B; IV A	Undesirable (ALMA decision required)
I E; II E; III C; IV B	Acceptable with review by ALMA
III D, E; IV C, IV D, IV E	Acceptable without review by ALMA

Table 8.3.2-4 - Hazard acceptability matrix

8.3.2.4 Requirements on Operational Hazards

None of the items in the following list (not meant to be exhaustive) shall lead to an unacceptable or undesirable hazard risk for the antenna or human beings:

- One or two independent operator errors;
- One operator error plus one hardware failure;
- One or two hardware failures;
- One or two software failures;
- Partial or complete loss of energy supplied to the antenna;
- Emergency braking of the antenna;
- OBE or MLE earthquakes happening for whatever position of the antenna;
- Wind loads.

Any failure leading to a loss of the base, the yoke, the BUS, the feed legs of the quadripod, or the subreflector shall be considered as "catastrophic".

8.3.2.5 Hazard Analysis

The purpose of a Hazard Analysis is to identify safety critical areas, evaluate hazards, and identify the safety measurement to be used.

A Hazard Analysis shall list all possible hazards -including an assessment of their severity (Section 8.3.2.1) and probability (Section 8.3.2.2) and shall show that safety considerations are included in all stages of the project including training, maintenance, transport, etc..

Safety provisions and alternatives needed to eliminate hazards or reduce their associated risk to a level acceptable to ALMA shall be described. As the design of the system progresses the Hazard Analysis shall be kept up to date reflecting new considerations, data and/or information. The following issues shall be considered:

a. All hazards that applicable to the system as per AD [7].

b. Safety related interface considerations among various elements of the system, e.g. material compatibility, electromagnetic interference, inadvertent activation, fire initiation and propagation, hardware and software controls etc.

c. All items listed in section 8.3.2.4.

d. Environmental hazards including transport, handling and operating environments,

e. All hazards related to operating, testing, maintenance and emergency procedures.

f. All other possible hazards.

g. A description of any risk reduction methods employed for each hazard like safety related equipment, safeguards, interlocks, system redundancy, hardware or software fail-safe design considerations etc. taking into account the design requirements noted down in section 8.3.4.

8.3.3 SAFETY COMPLIANCE ASSESSMENT

A Safety Compliance Assessment report is a collection of the entire safety related documentation relevant to the project.

As a minimum, the following information shall be part of that report:

- A brief description of the system and its domain.
- A brief description of the sub-systems and the boundaries between them.
- A description of the system functions and safety features.
- The Hazard Analysis (as mentioned in Section 8.3.2.5).
- The results of any audits carried out, tests performed (e.g. EMC, safety) or any other analyses related to safety.
- Reference to all standards and sources used including versions, date and status
- Identification of specialized procedures, skills and training (example operator training, lock-out).
- Conclusive statement on conformity.

A safety compliance assessment shall be documented in a Safety Compliance Assessment report. The Safety Compliance Assessment report shall contain the following information:

8.3.4 SAFETY DESIGN REQUIREMENTS

8.3.4.1 Fire safety

Smoke detectors are required in any equipment compartment in the base of the antenna and in the receiver cabin and shall be interlocked to shunt trip all electric power in the antenna. When smoke is detected the detector shall immediately close a contact which will be used by ALMA for a remote fire alarm and will energize a local audible alarm. The shunt trip of all power shall occur 5 seconds after smoke detection. Emergency power for the smoke detectors and local alarm shall utilize "Gel-cells" with a minimal reserve of 6 hours.

8.3.4.2 Mechanical Safety

For each component under design all the possible criteria of mechanical failure relevant to the component under examination shall be considered (strength, fatigue, buckling, etc.).

Unless otherwise required by the Standards applicable to this Technical Specification or by any applicable standard the minimum safety margins to be used are those provided herein.

A minimum stress safety margin of 1.5 with respect to the yield point has to be used in the design of all those mechanical components, which in case of a failure lead to an unacceptable or undesirable hazard risk.

This stress safety factor shall be reduced to 1.1 in case of survival and accidental conditions.

For metallic materials where the relevant failure criteria is not linked to plasticity (example fatigue), an equivalent stress safety factor of 1.5 shall be used in the design of all those mechanical components, which in case of a failure lead to an unacceptable or undesirable hazard risk.

For CFRP parts the equivalent stress safety factor shall be applied to the relevant failure mode to be considered for the part under examination. All relevant failure criteria shall be considered (delamination, fatigue, cracking, gluing failure etc…) An equivalent stress safety factor of 1.5 shall be used in the design of all those components, which in case of a failure lead to an unacceptable or undesirable hazard risk. This value applies also in case of accidental and survival conditions.

8.3.4.3 Electrical Safety

Electrical equipment installed on the antenna shall comply with their relevant international or US product standard taking into account the essential safety principles given in AD [7].

The Antenna as a whole shall be in conformity with AD [6], AD [9] (either IEC 60204-1 or NFPA 79) and with AD [15] (IEC 61140).

Electrical installations and equipment shall be specifically built and/or derated in order to safely perform their intended functions under the applicable environmental conditions (in particular, but not exclusively, under the reduced cooling and insulation capacities of the air at 5000 m above sea level). Insulation shall be coordinated in conformity with AD [14](IEC 60664) while taking into account the altitude of about 5000 m above sea level.

The antenna shall be designed, manufactured and erected to exhibit functional safety with regard to electromagnetic phenomena. To this purpose the methodology specified by AD [26] (in particular, by its 'Part 1-2: General - Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena') shall be adhered to.

Influence onto the antenna safety of sources of electromagnetic disturbances internal to the antenna itself shall be considered in relation with the antenna design.

8.3.4.4 Hydraulic Safety

Any hydraulic systems shall be designed in accordance with AD [16].

8.3.4.5 Pneumatic Safety

Any compressed air piping, including connections of compressed air system shall be designed in accordance with AD [13].

8.3.4.6 Handling, Transport and Storage Safety

The design of the antenna shall incorporate all means necessary to preclude or limit hazards to personnel and equipment during assembly, disassembly, test, transport, transport on site and short/long term storage of the complete antenna and/or parts thereof.

8.3.4.7 Toxic Substances

No use of toxic substance (asbestos, formaldehyde, lead….) and of their derivatives shall be made in the antenna. Insulation materials and paints specifications shall be reviewed by ALMA.

8.3.4.8 Confined Space

Considerations of confined space in the sense of AD [12] shall be taken into account in the design where applicable (example: base, yoke, etc.).

8.3.4.9 Miscellaneous

- No antenna part shall be able to fall onto the antenna reflector during operation or transport.
- As a general rule all safety relevant screw and bolts shall be secured or glued (during assembly or by using of special fixtures).
- Transport, lifting, hoisting devices and similar equipment shall be approved by an officially recognized independent verification agency (TÜV, UL, Bureau Veritas or similar institution).

8.3.5 SECURITY

Reasonable protection against unauthorized personnel access and theft shall be provided in the antenna by means of lockable and caged access ladder, locks on cabinets, doors and similar design provisions. Sensors shall be installed to monitor the condition "door open" and to relay the information to the ACU in order to detect unauthorized intrusion.

9 REQUIREMENTS FOR DESIGN AND CONSTRUCTION

9.1 ANALYSES AND DESIGN REQUIREMENTS

9.1.1 FINITE ELEMENT STRUCTURAL ANALYSES

All the Finite Element Analyses necessary for the verification of the performance of the antenna must be performed with an internationally recognized numerical code (ANSYS preferred). The structural models used shall be adapted to the particular analysis for which they are going to be used and shall be accurate enough to provide a good description of the behavior of the structure under examination in terms of displacements, stress and frequencies.

The analysis error due to mesh discretization shall be $\leq$ 10% in terms of FE internal criteria like the "Percentage error in energy norm". Alternatively this type of error can be evaluated by mesh refining. The verification of the accuracy of the modal analysis by experimental methods is in any case the preferred solution.

The analyses which have mandatorily to be performed are listed and specified here below. In case during the design phase it appears that other analyses are necessary the list below shall not be considered exhaustive.

9.1.1.1 Static analysis

Static analyses shall be used in the calculation of the effect of:

- Gravity loads (stress and deflection)
- Emergency Braking (stresses)
- Thermal deformation (input loads derived from the thermal analysis)
- Wind under primary operating conditions (deflections)
- Wind under survival conditions (stresses).
- Transport conditions (stresses)

9.1.1.2 Modal analysis

A modal analysis shall be performed in order to obtain accurate information concerning the eigenfrequencies and the eigenmodes of the antenna, when integrated in the antenna station, i.e. the combined stiffness of the soil and foundation of the antenna stations shall be adequately represented in the dynamic FE Model. The number of degrees of freedom shall be such as to have a good representation of the frequency range required. Care must be exerted to correctly represent the boundary conditions of the system under examination.

9.1.1.3 Seismic analysis

The structural model used for the seismic analysis shall adequately represent the distribution of stiffness and mass so that all significant deformation shapes and inertia forces are properly accounted for under the seismic action considered. Non-structural elements[4], which may influence the response of the main resisting structural system, shall also be accounted for. The response of all modes of vibration contributing significantly to the global response shall be taken into account. This may be demonstrated by either of the following:

- The sum of the effective modal masses for the modes taken into account amounts to at least 80 % of the total mass of the structure.
- All frequencies below 50 Hz shall be taken into account.

The above conditions have to be verified for each spatial direction.

The seismic analysis shall be based on the modal response spectrum technique, using a linear-elastic model of the structure and the design response spectra for MLE given in AD [2]. The applicable percentage of critical damping to be used is 1.5 % of critical damping.

The Square Root Sum of the Square method (SRSS) shall be used in order to combine the contribution of the various modal responses. The three spatial components of the response shall also be combined with the SRSS method. Alternatively, the combination rules for the modal and spatial components may be applied according to the provisions of AD [19].

9.1.1.4 Wind analysis

The force distribution on the antenna caused by primary operating conditions can be derived by either of the following:

- Adequate Computational Fluid Dynamic (CFD) analysis.
- Extrapolated wind tunnel measurement results of similar structure.

The force distribution caused by survival or accidental wind loads may be derived from applicable document AD [18], an equivalent wind load norm or from a CFD analysis. These forces may be applied as quasi-static.

9.1.2 THERMAL MODELING AND ANALYSIS

A thermal model of the antenna shall be used to compute the temperature distribution in the antenna during daytime Primary Operating conditions.

The thermal model shall be able to simulate adequately the effects caused by thermal conduction, convection and radiation (solar flux) as specified in section 4.4.3. The calculated temperature distribution shall be applied as thermal load to the structural FE model to predict the thermal error budget contribution.

---

[4] Architectural, mechanical or electrical element, system or component which, whether due to lack of strength or the way it is connected to the structure, is not considered in the seismic design as load carrying element.

9.1.3 STRESS ANALYSIS AND LOAD COMBINATION

A detailed stress analysis of the Antenna shall be performed. The stress analysis shall combine the individual design loads and conditions specified under section 4.4. In general the load combinations to be verified are given herein, whereby for specific components different loads combination may apply. No more than one accidental conditions shall be applied at the time.

LOAD COMBINATION OPERATIONAL CONDITIONS
Gravity + Thermal (secondary) + Wind (20 m/sec)
Gravity + Thermal (primary)+ Wind (6.4 m/sec) + Fast Switching

LOAD COMBINATION ACCIDENTAL CONDITIONS
Gravity + Thermal (secondary) + Wind (30 m/sec) + Emergency braking
Gravity + Wind (20 m/s) + Transporter Handling
LOAD COMBINATION SURVIVAL CONDITIONS
Gravity + Wind (65m/sec)
Gravity + Thermal (-30 °C) + Wind (30 m/s)
Gravity + Wind (30 m/sec) + Icing + Snow
Gravity + Seismic (MLE) + Wind (20 m/s)

The result of the Load Combination Operational shall be evaluated both for the verification of:

- Maximum stress criteria (yield, microyield, tensile stress, etc..)
- Fatigue criteria (high and low cycle fatigue or whatever failure criteria are applicable for the materials used)
- CFRP strength criteria

The result of the Load Combination Accidental and Survival shall be evaluated for:

- Maximum stress criteria (yield, brittle rupture)
- CFRP strength criteria

9.1.4 CONTROL LOOP DESIGN AND ANALYSIS

The contractor shall design for each of the functions to be controlled an individual control law. For each of the functions to be controlled the stability margins shall be computed.

The contractor shall perform a dynamic simulations of the various function and control loops. The main purpose of these simulations is to confirm the fulfillment of the different relevant requirements. The dynamic simulation shall include the effect of all non-linear effects like friction, stick-slip, sensor noise, etc.

9.1.5 RELIABILITY AVAILABILITY MAINTAINABILITY ANALYSIS

A Reliability, Availability Maintainability analysis shall be performed in order to locate weak design points and to provide an indication whether the design meets the requirements of Sections 8.1 and 8.2. Unless the contractor wants to apply a recognized reliability analysis method, which fits his experience and can be agreed upon, ALMA suggests to apply the Parts Count Method for prediction the reliability of the system as described in the MIL-HDBK-217F or Telcordia calculation methods. For non electronic parts the values of NPRD-95 "non-electronic Parts Reliability Data, of the US department of Defense can be used, or alternatively data from manufacturers or other database may be used.

Another, but more time consuming – and considered more accurate method, the Parts Stress Analysis Prediction, is described in the same publication, available for use. This may be used in the case where the result of the Parts Count method does not comply with the ALMA reliability requirement. The MIL-HDBK-217F describes in detail both methods.

The ALMA antenna will be operated at the AOS an altitude in excess of 5000m, in an environment where temperature and pressure might decrease the MTBF for electronics as well as for the mechanical equipment. The environmental conditions on the ALMA site shall be taken into specific account in the reliability prediction, failure rates shall be multiplied with the environmental factor (similar to AUC (for Uninhabited Cargo Aircraft), as it is found in MIL-HDBK-217F.

Very limited maintenance can be performed at the AOS. The fulfillment of the maintainability requirements shall take into account all aspects of preventive and corrective maintenance on the basis of the reliability analysis. The overall availability number of the antenna shall be computed on the basis of the Mean Time Between Failures (MTBF), the Mean Time To Repair (MTTR) and the Time for Preventive Maintenance (TPM)

9.1.6 HIGH ALTITUDE ANALYSIS

The effect of the environmental conditions to be encountered at the AOS, with particular respect to the altitude and the resulting lower air density, shall be analyzed and reported in a analysis. The analysis shall take into account all anticipated effects, electrical (reduced cooling, reduced insulation capacity, ozone concentration), thermal, etc. and explain the measures adopted to cope with them.

The analysis shall provide a summary table showing how all the environmental conditions has been addressed in a systematic way for all equipment.

The analysis shall also document the measures taken at design level in order to support the maintenance to be performed at the AOS, under consideration of the reduced capacities of employees working at high altitude.

9.2 ELECTROMAGNETIC COMPATIBILITY REQUIREMENTS

9.2.1 GENERAL

The ALMA antennas will operate outdoor and will be subject to direct lightning flashes. Requirements on lightning protection and grounding can be found in section 6.12.3.

9.2.2 INTRA- AND INTER-SYSTEM EMC

The ALMA antenna shall exhibit complete electromagnetic compatibility (EMC) among its parts, components, devices and equipment (intra-system electromagnetic compatibility).

Prevention of electromagnetic interference (EMI) between the ALMA antenna and systems not belonging to the antenna (inter-system electromagnetic compatibility) shall be a major driver in the design and construction of the Antenna.

The following requirements shall be fulfilled as a minimum to achieve both intra- and inter-system EMC. The detailed implementation of the EMC design measures required hereafter is liable to be modified provided that the contractor may provide undisputable quantitatively based evidence that the alternative EMC design measure(s) he proposes be at least as effective as the one specified. These changes shall be submitted to ALMA for approval.

Control circuits, drive motors amplifiers, and switching devices shall be designed and constructed taking into account the requirements concerning radiated and conducted electromagnetic energy. In particular, all motor leads, both power and control, shall be filtered.

All relay contacts and actuators shall be properly bypassed with snubber circuits, shielded and/or filtered.

All amplifiers and oscillators shall be mounted in shielded enclosures that will provide effective shielding of radio frequency energy.

Silicon-controlled rectifier switching devices shall not be used unless phase controlled and zero current crossing switching techniques are used.

No gaseous discharge devices, except noise sources for test, shall be employed.

Means shall be employed to reduce static electricity and the consequent radio frequency noise generated in any rotating machinery. Immunity to ESD shall be according to AD [5].

All displays (LCD, plasma, LED, CRT) shall have a RFI shield in front of the display to avoid radiated RFI.

All digital equipment, whether a simple logic circuit, embedded CPU, or rack mounted PC shall be shielded and have its AC power line and modem/LAN line(s) filtered at the chassis.

The receiver cabin shall be provided with an effective, shielded enclosure constituted by a durable continuous metallic surface. Such an enclosure shall exhibit a shielding effectiveness (SE) such that no electromagnetic interference is able to disturb the antenna itself or nearby antennas. Durable RFI shielding shall be provided on the cabin door and on all other shields penetrations and discontinuities (seams, apertures, vents, cable and pipe penetrations, screw, etc.). The measured shielding effectiveness shall be 20 dB at 12 GHz.

Should the base room host any relevant electrical and/or electronic equipment, it shall be shielded. The measured shielding effectiveness shall be 10 dB at 12 GHz.

All wires and cables provided by the Contractor that enter the receiver cabin shall have RFI suppression. ALMA will be responsible for shielding the receiver cabin vertex hole.

The frequency range to be covered by these design measures for radiated radio-frequency interference (RFI) suppression shall extend from 50 MHz up to the 12 GHz.

9.2.3 EMISSION LIMITS

As any piece of electrical/electronic equipment, the ALMA antenna is liable to emit conducted as well as radiated electromagnetic disturbances. Objective of this section is to set the emission limits that the ALMA antenna shall conform to.

The emission limits are grouped in the following according to the particular port[5] through which they may be emitted.

9.2.3.1 Harmonic currents

Port: AC Mains

The harmonic currents injected by ALMA Antenna into ALMA site power distribution system shall not exceed the percent ratios specified by AD [5] section "2.4.1.1 Harmonic currents".

9.2.3.2 Voltage fluctuations and flicker

Port: AC Mains

Voltage fluctuations and flicker injected into the ALMA power distribution system by the ALMA Antenna shall not exceed the limits standardized by Part 3-5 of AD [26] [IEC 61000-3-5].

9.2.3.3 Conducted RF disturbance voltage

Port: AC Mains

The ALMA antenna shall not emit conducted radio-frequency terminal disturbance voltages in excess of the values specified by AD [5] section "2.4.1.2 Conducted RF disturbance voltage".

5
Port: Particular interface of the specified apparatus with the external electromagnetic environment. **Enclosure port**: The physical boundary of the apparatus through which electromagnetic fields may radiate or impinge.

9.2.3.4 Radiated emission

Port: Enclosure

The electromagnetic radiation (radiated field) emitted by the ALMA antenna shall conform to the limits specified by AD [5] section "2.4.2.1 Radiated field emission limits".

The electrical and electronic equipment mounted onto/integrated into the antenna shall not emit RF radiated disturbances that exceed the following limits:

≤ 0.1 nanoW within any RBW = 100 kHz over the range f = 11 to 12 GHz

≤ 0.1 microW within any RBW = 1 GHz. over the range f = 4 to 12 GHz

9.2.4 IMMUNITY LIMITS

ALMA antenna shall be immune to electromagnetic disturbances injected into or impinging onto it. The immunity exhibited by ALMA antenna shall conform to the immunity limits specified by the present section.

Functional/performance criteria shall be adopted for the ALMA antenna as defined by AD [5] section "2.3.1 Performance criteria".

More information on the immunity limits specified hereafter may be found in AD [5] section "2.3 Immunity requirements"

9.2.4.1 Immunity limits – Input and output AC power ports

	Environmental phenomenon (disturbance)	Immunity limits and other specifications (See note 1.)	Units	Performance criterion	Verification method (see note 7.)
1	Harmonic voltages - Individual harmonics	Immunity limits = 1.6 × v_n (See note 2.)	% of Un	A	RoD; A
2	Harmonic voltages - Total Harmonic Distortion THD	THD = 8	% of Un	A	RoD; A
3	Rectangular (step) voltage fluctuations	ΔU = ±12 repetition period T = 5÷10 duration t = 2÷3	% of Un s s	A	RoD; A
4	Voltage dips (sags) (See note 3.)	ΔU_1 = -30 duration 0.5 periods ΔU_2 = -60 duration 5 periods	% of Un % of Un	B C	RoD; A
5	Voltage interruptions (See note 3.)	$\Delta U_2 \leq$ -95 duration 250 periods	% of Un	C	RoD; A
7	Conducted disturbances induced by RF fields (See note 4.)	E = 3 f = 0.15 to 80 AM modulation at 1 kHz: 80	V MHz %	A	RoD; A
8	Voltage (current) surges (See note 5.)	U = ±2.0 kV ±10% line-to-line U = ±4.0 kV ±10% line-to-earth Tr/Th =1,2/50 µs (8/20 µs)		B	RoD, A, T
9	Fast transient bursts (See note 6.)	U = ±2.0 kV ±10% Tr/Th =5/50 µs, f_{rep} = 5 kHz		B	T

NOTES
1. The basic standards for all these disturbances are the applicable parts of AD [26] [IEC 61000]
2. v_n = harmonic voltage compatibility levels specified by section 4.1.1.1 of AD [3].
3. Applicable only to AC input ports; voltage shift at zero crossing.
4. The test level specified is the r.m.s. value of the unmodulated carrier. The test level can also be defined as the equivalent current into a 150 Ω load.
5. Should the antenna AC power input have an impedance lower than that of the ALMA site power distribution system at the interface with the antenna, the antenna AC power input shall be immune to corresponding current surges with Tr/Th = 8/20 µs.
6. Applied also to PE terminals.
7. RoD = Review of Design; A = Analysis; I = Inspection; T = Test

Table 9.2.4-1 – Immunity limits – Input and output AC power ports

9.2.4.2 Immunity limits – Enclosure port

	Environmental phenomenon (disturbance)	Immunity limits and other specifications (See note 1.)		Performance criterion	Verification method (see note 3.)
			Units		
1	Electrostatic discharge - ESD	Contact discharge 2 to 8 kV in 2 kV increments		A up to 4 kV B above 4 kV	T
		Air discharge 2 to 15 kV in 2 kV increments		A up to 8 kV B above 8 kV	
2	Radiated EM field. Amplitude modulated	E = 10 f = 80 to 1000 AM modulation at 1 kHz: 80	V/m MHz %	A	RoD, A, T
3	Radiated EM field. Keyed carrier (See note 2.)	E = 10 f = 900 ± 5 Duty cycle 50 Repetition frequency 200	V/m MHz % Hz	A	RoD, A

NOTES
1. The basic standards for all these disturbances are the applicable parts of AD [26] [IEC 61000]
2. The specified test level is prior to keying.
3. RoD = Review of Design; A = Analysis; I = Inspection; T = Test

Table 9.2.4-2 – Immunity limits – Enclosure port

9.2.4.3 Immunity limits – I/O, control and signal ports

	Environmental phenomenon (disturbance)	Immunity limits and other specifications (See note 1.)		Performance criterion	Verification method (See note 3.)
1	Conducted disturbances induced by RF fields (See note 2.)	E = 3 f = 0.15 to 80 AM modulation at 1 kHz: 80	V MHz %	A	RoD, A
2	Fast transient bursts	U = ±0.5 kV ±10% Tr/Th =5/50 μs repetition frequency f = 5 kHz		B	RoD, A

NOTES

1. The basic standard for these disturbances are the applicable parts of AD [26] [IEC 61000]
2. Applicable only to ports interfacing with cables whose total length may exceed 3 m. The test level specified is the r.m.s. value of the unmodulated carrier. The test level can also be defined as the equivalent current into a 150 Ω load.
3. RoD = Review of Design; A = Analysis; I = Inspection; T = Test

Table 9.2.4-3 – Immunity limits – I/O, control and signal ports

9.2.5 EMC CONTROL PLAN

The Contractor shall submit to ALMA for approval an EMC Control Plan that shall describe the design measures implemented to conform to the requirements set in this specification about EMC, grounding, protection against lightning and LEMP.

The EMC Control Plan shall be prepared according to the procedures and purposes set in the AD [27] (VG 95374 "Electromagnetic Compatibility (EMC) including Electromagnetic Pulse (EMP) and Lightning Protection - Programme and Procedures " published (also in English) by the German "*Bundesamt für Wehrtechnik und Beschaffung*"). Similar reference standard/s may be followed by the Contractor, provided it/they be previously submitted to ALMA for approval.

9.3 MATERIALS PARTS AND PROCESSES

9.3.1 TYPE OF STEEL

The steel used in the antenna mount shall be a carbon or a low-alloys steel. The selection of the steel shall take into account the low temperature to be expected during operation and stow of the antenna, under the point of view of embrittlement. In particular the nil-ductility transition temperature of the selected steel shall not exceed -45ºC. The nil-ductility transition temperature is the temperature at which the material starts to exhibit cleavage fracture with very little evidence of notch ductility.

When necessary (example: gears and pinions, if applicable) materials with suitable hardness or surface hardened shall be used, in order to ensure the life of the system.

9.3.2 STRESS RELIEVING

All structural welded parts shall be stress relieved by means of an appropriate method, in order to reduce stresses and ensure dimensional stability (unless proven by the Contractor to be unnecessary)

9.3.3 CFRP

Carbon Fiber Reinforced Plastic (CFRP) material and processes shall be selected, examined and if necessary qualified under the point of view of strength, fatigue and life duration. All CFRP structures shall be protected against solar radiation and humidity with suitable paints and or sunshades.

9.3.4 FASTENERS

All fasteners shall be metric; however, allowances may be made for fasteners that are on off-the-shelf units. The use of standard metric cross-sections for construction materials is preferred but will not be required if such use results in increased cost.

9.3.5 PAINTS

To limit the effect of solar heating and associated differential expansion of structural members and to protect the structure against atmospheric corrosion, the antenna structure, with exception of the reflector surface, shall be painted with white solar reflecting paint.

The paint shall be chosen to last at least 10 years before repainting is necessary. Special attention will be given to the severe solar radiation environment on the high-altitude site. The Contractor will provide a specification for material, preparation, application and quality control testing for the paint system for approval by ALMA.

9.3.6 SURFACE TREATMENT

Unpainted surfaces shall be treated against corrosion. In this case the bonding requirements specified in AD [6] shall be adhered to.

9.4 THERMAL INSULATION

Thermal insulation when used in an exterior application by the contractor shall be protected with a metal cover.

9.5 NAME PLATES AND PRODUCT MARKING

As a general rule the main parts and all exchangeable units shall be equipped with nameplates which are visible after installation of the part/unit and which contain the following information:

- Part/unit name
- Drawing number including revision
- Serial number
- Manufacturing month and year
- Name of manufacturer.

Alternatively a system of marking based on barcodes or similar system may be used upon approval by ALMA.

9.6 LABELS

- All cables and switches, junction boxes, sensors, and similar equipment shall be labeled.
- Electrical cabinets, switch panels, UPS, and all electrical equipment which can be manually operated or is relevant for safety shall be labeled in English and Spanish.

9.7 WORKMANSHIP

Only methods and procedures which are state of the art in high precision mechanics, hydraulics and pneumatics, optical engineering, electrical and electronics development, design, and manufacturing shall be used.

9.8 INTERCHANGEABILITY

The antennas produced on the basis of this specification shall be, to the extent of possible based on the same design and the same components, in order to achieve interchangeability.

Items shall be designed in such a way that antenna parts can be installed using the same procedures, and tools.

10 DOCUMENTATION

10.1 TECHNICAL DOCUMENTATION

All documentation related to the antenna shall meet the following requirements:

- The language used for written documentation shall be English.
- The electronic document formats are Word and Adobe.
- Layouts of electronic circuits and printed circuit boards shall also be provided in electronically readable form. The ALMA preferred formats are ORCAD for electronic circuit diagrams and AutoCAD format for printed circuit board layouts;
- Drawings shall be generated according to ISO standards and use metric units
- The preferred CAD system used is AutoCAD.
- Finite Element models and results, as part of analysis reports, shall be in ANSYS format provided in electronic format.

The Contractor shall follow the requirements of AD [8]. Derogation from the above shall be agreed by ALMA.

10.2 SOFTWARE AND SOFTWARE DOCUMENTATION

The ACU software and any other specially developed software, including Utility module are deliverables. The SW shall be delivered in source and object form, together with all procedure and tests necessary for installation, testing, upgrades and maintenance.

- Software must be tagged with suitable version numbers that allow to identify (also on-line remotely) a consistent Release
- User manuals of software developed under this specification and of any other commercial software used (controllers embedded software, special tools, etc)
- Software maintenance and installation upgrades documentation
- Full Test and Acceptance procedures

11 VERIFICATION AND QUALITY ASSURANCE

11.1 GENERAL CONSIDERATIONS

The verification of the compliance of the antenna with the specified requirement shall be done according to the following philosophy:

a) Verification of the design at the Pre-Production Design Review (PPDR):

This verification shall demonstrate that the detailed design is able to meet the specified requirements with a minimum of development risk. This verification may include hardware manufacturing and testing.. Hardware and software tests are required in all those areas where the capability to meet the specified requirements cannot be demonstrated by other means with a high degree of confidence.

b) Acceptance Testing in Chile

At the Acceptance extensive testing of the fully integrated antenna is performed, and the complete compliance with the technical specification (including ICD) is verified.

In addition the completeness and correctness of all necessary documentation is checked

For the first Antenna:

For the first antenna the verification to be performed is defined by the Performance Verification matrix of Table 11.2-a. The table shows the verification methods to be applied for the verification of each performance requirement for the first Antenna.

For the Antenna #2 to N:

The contractor may propose a reduced set of verification matrix. As a general rule all test performed on the first unit shall be repeated unless it can be reasonably demonstrated that the verification of compliance can be obtained by analogy with the first unit. A reduced verification matrix may be proposed by the Contractor and be submitted to ALMA approval.

Design changes, although not foreseen by the Statement of Work, demand a repetition of the subsystem and system related tests.

All verification activities shall be properly planned, performed and documented. Modification of the verification methods may be proposed by the contractor but must be approved by ALMA.

11.2 PERFORMANCE VERIFICATION MATRIX

In addition to the inspections procedures performed according to the quality assurance requirements, three methods of verification shall be applied to check that performance requirements of the antenna are met:

-Verification by design
The performance shall be demonstrated by a proper design, which will be checked by ALMA during the design phase of the contract by review of the design documentation.

-Verification by analysis
The fulfillment of the specified performance shall be demonstrated by appropriate analysis (hand calculations, finite element analysis, thermal modeling, etc.), which will be checked by ALMA during the design phase.

-Verification by test
The compliance of the developed item / assembly / unit with the specified performance shall be demonstrated by tests. This includes also inspections and measurements

Para. No.	**Requirement**	**Design**	**Analysis**	**Test per Section: (*)**
4.2.1	Interface with the Antenna Stations	X		X
4.2.2	Interface with the ALMA Power Distribution System	X		X
4.2.3	Interface with the Antenna Transporter	X		X
4.2.4	Interface with the Front End	X		X
4.2.5	Interface with the Back End	X		X
4.2.6	Interface with ALMA Computing and Control Software	X		X
4.2.7	Interface with the External (ALMA) Cables and Piping	X		X
4.2.8	Interface with Front End Service Vehicle	X		X
4.2.9	Interface with the Optical Pointing Telescope	X	X	X
4.2.10	Interface with the Holography Receiver	X		X
4.3.2.	Optical Configuration	X		
4.3.3.1	Close packing	X		X
4.3.3.2	Height	X		X
4.3.4	Antenna Volume during Transport	X		X
4.3.5	Mass	X		11.4.1
4.3.6	Location of the Center of Mass	X		
4.4	Operating Parameters and conditions	X	X	
4.4.7.3	Emergency Braking		X	X
5.2.1	Range Requirements	X		X
5.2.2	Velocity and Acceleration		X	X
5.2.3	Stow Positions	X		X
5.2.5	Close Packing Park Position	X		X

5.2.6.1	Azimuth axis			X
5.2.6.2	Elevation axis			X
5.2.6.3	Azimuth and elevation axis offset		X	X
5.2.6.4.	Reflector axis and Elevation axis			X
5.2..7	Subreflector stability		X	(X)
5.3.1	Repeatable Pointing Errors	X		11.4.4
5.3.2.1	Absolute Non-repeatable Pointing Errors		X	11.4.4
5.3.2.2	Offset Pointing and Tracking Errors		X	11.4.4
5.4.1	Fast Switching Phase Calibration		X	X
5.4.2	On the Fly Total Power Mapping		X	X
5.4.3	On the Fly Interferometric Mosaicking		X	X
5.4.4	Step Response		X	X
5.5	Antenna Surface Accuracy Requirements		X	11.4.2, 11.4.3
5.6.1	Repeatable Residual Delay		X	X
5.6.2	Non-Repeatable Residual Delay		X	X
5.7	Solar Observations	X	X	X
5.8	Low Noise	X	X	11.4.5
5.9	Transportability	X		X
6.2.1	Base	X		X
6.2.2	Main Axes Drives	X	X	X
6.2.3	Main Axes Brakes	X	X	X
6.2.4	Axes limits and stops	X		X
6.2.5	Stow pins	X		X
6.3.1	Cabin Physical Dimensions and Characteristics	X		X
6.3.2	Receiver Flange	X	X	X
6.3.3	Electrical Requirements	X		X
6.3.4	Thermal Requirements		X	X
6.3.5	RF Membrane	X		X
6.4	Reflector Panels	X		X
6.5	Panels Adjusters	X		X
6.6	Backup Structure	X	X	
6.7	Feed Shutter	X		X
6.8.1	Subreflector		X	X
6.8.1.1	Subreflector Central Cone	X		X
6.8.2	Subreflector Mechanism		X	X
6.8.3	Nutator Interface	X		X
6.8.4	Quadripod Structure	X		X

6.9.1.	Azimuth and Elevation Cable Wraps	X		X
6.9.2	ALMA Cables and Hoses	X		X
6.9.2.1	CAN-0 Cable requirement	X		X
6.9.3	On-Axis Cable Wrap	X		X
6.10.1	ACU General	X		
6.10.2	Local Control and Monitoring	X		X
6.10.3	Portable Control Unit	X		X
6.10.4	ACU Modes of Operation	X		X
6.10.5	Monitor and Control Digital Interface	X		X
6.10.6	Computing and Software	X		X
6.10.7	Interlocks	X		X
6.10.8	Fault Conditions			X
6.10.8.1	Automatic Survival Stow Conditions			X
6.10.9	Utility Module	X		X
6.10.10	Space Requirements	X		
6.11	Metrology	X		X
6.12.1	Power Distribution	X	X	X
6.12.2	Junction Boxes	X		X
6.12.3	Grounding, Protection against Lightning and LEMP	X		X
6.12.4	Single-Phase and Reverse Phase Protection	X		X
7.1	Receiver Cabin Equipment Handling	X		(X)
7.2.1	Access Platform	X		X
7.2.2	Access and Manholes	X		X
7.2.3	Access Ladders/Stairs	X		
7.4.1	Counterweight for Balancing	X		X
7.4.2	Service Equipment	X		X
7.4.3	Optical Telescope	X	X	
8.1	Lifetime and Reliability Requirements	X	X	
8.2.1	Maintenance Approach	X		X
8.2.2.1	Periodic Preventive Maintenance		X	X
8.2.2.2	Overhaul		X	
8.2.2.3	Alignment of the Primary Reflector			X
8.2.3	On-Site Repair / Corrective Maintenance			X
8.2.4	Monitoring Points and Test Routines	X		X
8.3	Safety	X	X	
8.3.4.1	Fire Safety	X		X

8.3.4.2	Mechanical Safety		X	
8.3.4.3	Electrical Safety	X		X
8.3.4.4	Hydraulic Safety	X		X
8.3.4.5	Pneumatic Safety	X		X
8.3.4.6	Handling, Transport, and Storage Safety	X		
8.3.4.7	Toxic Substances	X		
8.3.4.8	Confined Space	X		
8.3.4.9	Miscellaneous	X		X
8.3.5	Security	X		X
9.1.1	Finite Element Structural Analyses		X	
9.1.2	Thermal Modeling and Analysis		X	
9.1.3	Stress Analysis and Load Combination		X	
9.1.4	Control Loop Design and Analysis		X	
9.1.5.	Reliability Availability Maintainability Analysis		X	
9.1.5.	High Altitude Analysis		X	
9.2.2	Intra- and Inter-System EMC	X	X	11.4.6
9.2.3.1	Harmonic Currents		X	11.4.6
9.2.3.2	Voltage Fluctuations and Flicker	X		
9.2.3.3	Conducted RF Disturbance Voltage	X		11.4.6
9.2.3.4	Radiated Emission		X	11.4.6
9.2.4	Immunity Limits	X	X	11.4.6
9.2.5	EMC Control Plan		X	
9.3.1	Stress Relieving	X		
9.3.2	Fasteners	X		
9.3.3	Paints	X		X
9.3.4	Surface Treatment	X		X
9.4	Thermal Insulation	X		X
9.5	Name Plates and Product Marking	X		X
9.6	Labels			X
9.7	Workmanship			X
9.8	Interchangeability	X		

Table 11.2-a Performance verification matrix for the first antenna

Note (*): Tests which do not have an explicit reference shall be defined by the Contractor

11.3 QUALITY ASSURANCE REQUIREMENTS

In addition to the verification at acceptance as defined in Section 11.1, a Quality Assurance program shall be applied by the Contractor during manufacturing phase.

The quality assurance program to be executed by the contractor shall provide means for early detection of non-conformances, as well as for positive corrective actions. It shall also provide sufficient control to ensure conformance to the technical requirement of the present specification and of the applicable documents..

11.4 SPECIFIC TEST REQUIREMENTS

11.4.1 MASS

The mass budget of the antenna shall be validated by specific weight measurement of the major antenna assemblies.

11.4.2 INDIVIDUAL PANEL TESTING REQUIREMENTS

Each panel shall be inspected individually. The testing plan provided by the Contractor shall be based on the following considerations.

In measuring the manufacturing accuracy of each panel a grid of points shall be chosen such that each measured point represents approximately:

- 10 cm2 of panel surface area for all the panels of the first batch of panels and until the manufacturing process has been qualified and can be considered stable. The same applies if the manufacturing process is produced by separate machines or production lines.
- 30 cm2 of panel surface for successive panels.
- 10 cm2 of panel surface for selected panels within the various production batches.

The RMS error of the panel measurement method shall not exceed 25 percent of the panel RMS manufacturing accuracy.

11.4.3 SURFACE ACCURACY VERIFICATION

Prior to performing the surface accuracy testing with Holography for the first unit, and prior to deliver the unit #2 to N, the Contractor shall adjust the reflector surface to an RMS setting accuracy of 60 micrometers RMS. The Contractor shall conduct a survey of the primary reflector surface after adjustment using his instrument and personnel to demonstrate that the reflector as installed meets the coarse adjustment setting accuracy of 60 micrometers RMS with the antenna positioned at zenith. The Contractor shall propose to ALMA fro approval a measurement method of suitable accuracy to achieve this course setting.

In addition the Contractor shall prepare and execute a verification plan that demonstrates, by calculation and/or test, that all components of the primary reflector surface accuracy error budget under primary operating conditions, except reflector panel setting, have been achieved. This shall include verification of individual panels as per Section 11.4.2

Surveys shall be conducted at times of minimal wind and thermal loading (i.e., on windless nights) with the reflector positioned at zenith. Measurements shall be made by using reference points on the reflector panels adjacent to the panel adjusters. These measurements shall then be reduced to a RMS error from the best-fit paraboloid.

For the first antenna a complete verification and setting of the panel down to the specified value will be performed as part of acceptance testing, by using the Holography Receiver provided by ALMA. ALMA will be responsible for deriving the reflector surface data. These measurements will be given to the Contractor and the Contractor shall be responsible for setting the panels based on those measurements.

Minimum requirements for the Holographic measurements to begin are as the following:

- All panels must be installed and set to the initial panel setting by the Contractor as specified herein above (60 micrometer RMS), with the adjusters within +/- 2 mm of their nominal mid-range position.
- The reflector shall be aligned in order to meet the requirement of Section 5.2.5.4

For the antennas 2 to N, the holography test and setting will not be part of the acceptance testing. Requirements on the setting of panels and adjusters are still applicable.

11.4.4 Pointing Tests with the Optical Pointing Telescope

The verification of the certain elements of the pointing and tracking performance of the antenna shall be done with the pointing telescope provided by ALMA.

11.4.4.1 Repeatable Pointing Error

The performance of the antenna in term of blind pointing objects in the sky will be tested, but limited to the performance of the main drive.

In this test a reference star close to zenith will be pointed with the pointing telescope, and the actual position of the star will be input in the antenna SW, and considered as having a zero pointing error. After that a sufficient number of stars in a star catalogue will be pointed and the offset between the achieved position and the star position as indicated by the pointing telescope will be measured. The RMS of the offset will constitute the repeatable pointing error (this assume that the nor-repeatable error part in the measure is small compared to the maximum allowed repeatable pointing error of Section 5.3.1).

11.4.4.2 Absolute Non-repeatable Pointing Error

The performance of the antenna in term of blind pointing objects in the sky will be tested, but limited to the performance of the main drive. The test will be performed after introduction in the system of a pointing model as foreseen by ICD [06].

Once the pointing model is installed and refined a sufficient number of star from a star catalogue will be pointed and the RMS value of the error between the achieved positions and the actual stars position as measured by the pointing telescope will be recorded. After that the RMS value of the error will be computed, and constitute the absolute non repeatable pointing error. This value shall be comparable to the corresponding value of the error budget provided by the Contractor.

11.4.4.3 Offset pointing and tracking Error

The performance of the antenna in term of pointing and tracking will be verified by execution of 15 minutes sidereal tracking runs with offsets up to 2 degrees on the sky.

The error between the commanded position and the actual star position will be recorded at a sufficiently high rate with the pointing telescope and the RMS error will be computed. This value shall be comparable to the corresponding value of the error budget provided by the Contractor.

11.4.5 PANEL RF REFLECTIVITY

The RF reflectivity of the panels shall be validated by the use of tests performed on panel samples.

11.4.6 EMC TESTS

ALMA will perform EMC tests on the first antenna to be delivered prior to acceptance testing. The tests will cover safety related and general EMC aspects (emissions, immunity to ESD, surges, electric fast transients and RF fields, etc.). In addition shielding effectiveness and RF tests at frequencies 1 to 12GHz will be performed.

ALMA will perform a limited number of tests on the following units, after acceptance, on the base of design analogy. ALMA reserves its right to perform tests prior to acceptance in case of design modifications.

12 ANNEXES

DWG [01] Transport Design Volume
ANTD-34-00.00.00.-002-A-DWG

DWG [02] Clearance profile for passage in the Central Cluster
ANTD-34-00.00.00.-005-A-DWG

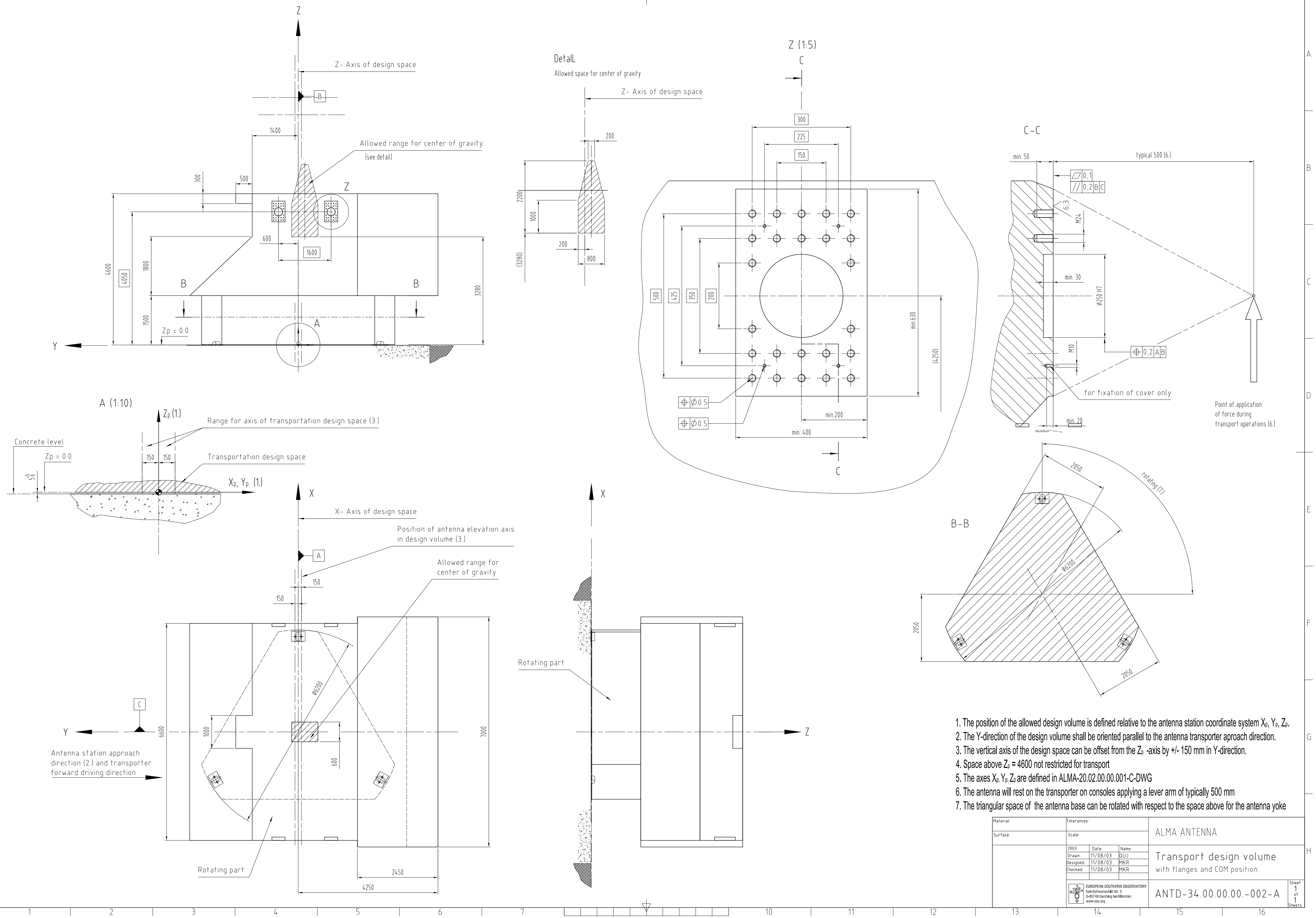
DWG [03] Receiver Installation Platform
ANTD-34-00.00.00.-010-A-DWG

DWG [04] Subreflector Central Cone
ANTD-34-00.00.00.-008-A-DWG

DWG [05] Optical Telescope Flange and Volume
ANTD-34-00.00.00.-009-A-DWG

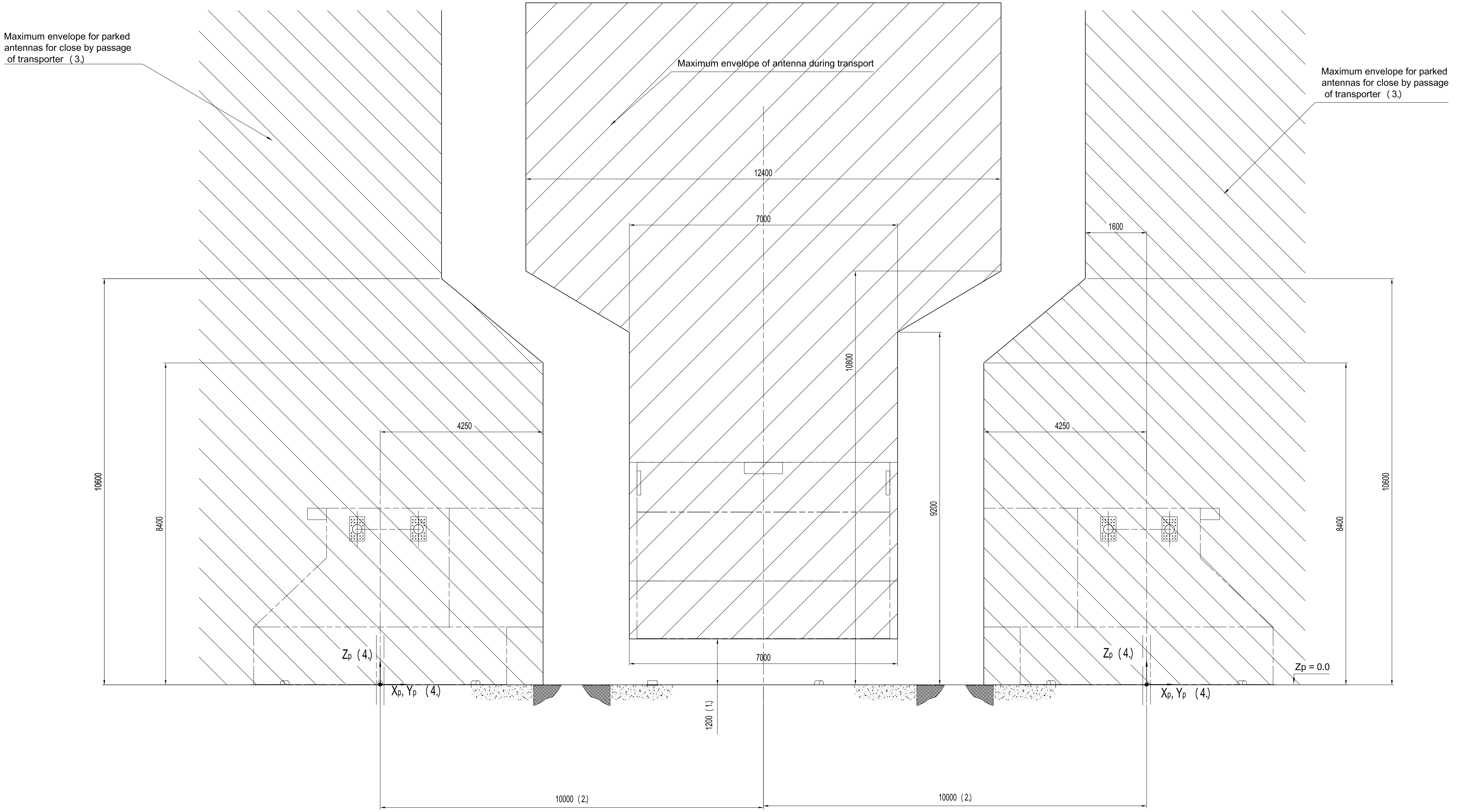
DWG [06] Apex Flange and Volume
ANTD-34-00.00.00.-003-A-DWG

DWG [07] On-Axis Cable Wrap
ANTD-34-00.00.00.-004-A-DWG



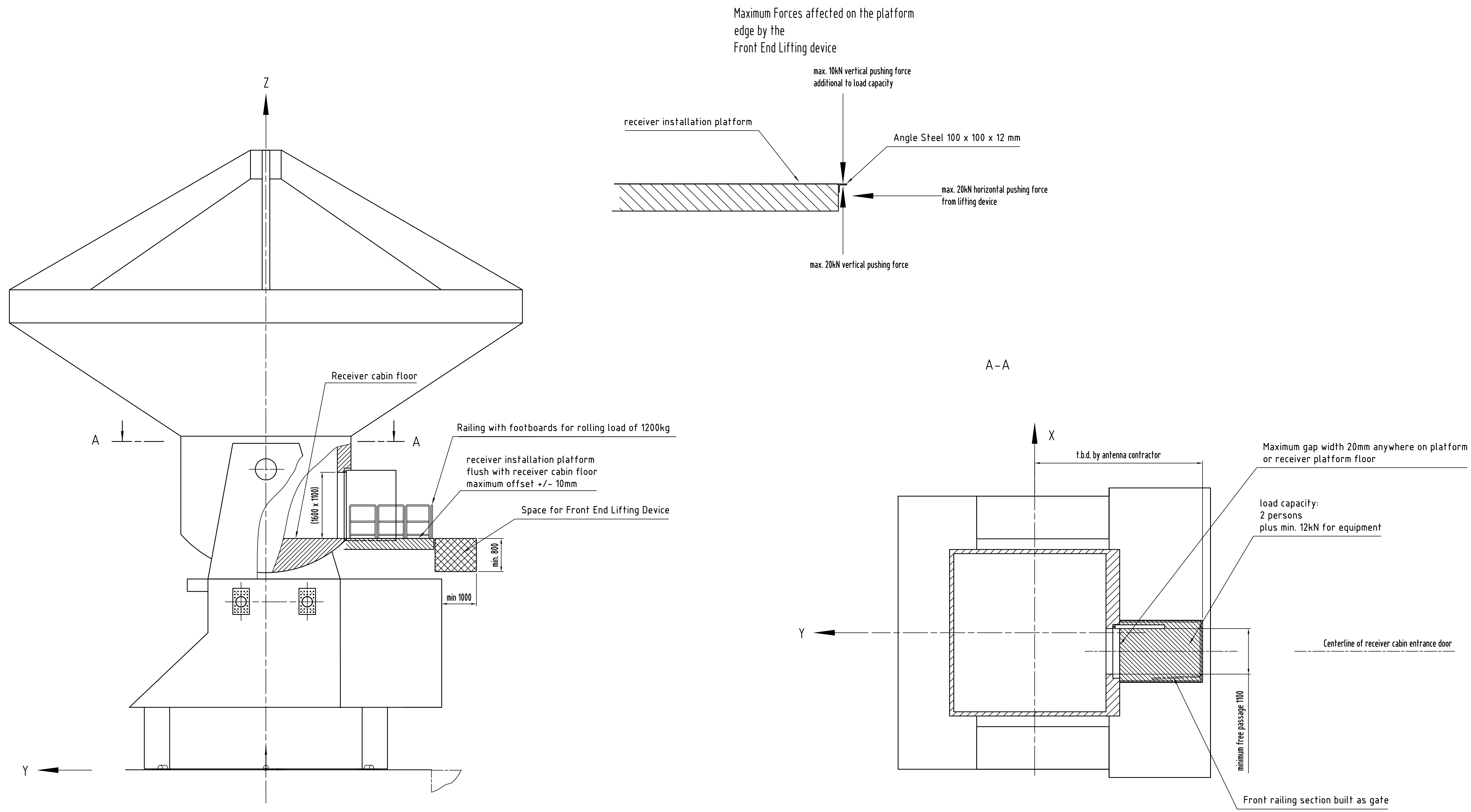
1. The position of the allowed design volume is defined relative to the antenna station coordinate system X_p, Y_p, Z_p.
2. The Y-direction of the design volume shall be oriented parallel to the antenna transporter aproach direction.
3. The vertical axis of the design space can be offset from the Z_p -axis by +/- 150 mm in Y-direction.
4. Space above Z_p = 4600 not restricted for transport
5. The axes X_p, Y_p, Z_p are defined in ALMA-20.02.00.00.001-C-DWG
6. The antenna will rest on the transporter on consoles applying a lever arm of typically 500 mm
7. The triangular space of the antenna base can be rotated with respect to the space above for the antenna yoke

Material:	Tolerances:			ALMA ANTENNA
Surface:	Scale:			
	2003	Date	Name	Transport design volume with flanges and COM position
	Drawn	11/08/03	QUJ	
	Designed	11/08/03	MKR	
	Checked	11/08/03	MKR	
	EUROPEAN SOUTHERN OBSERVATORY Karl-Schwarzschild-Str. 2 D-85748 Garching bei München www.eso.org			ANTD-34.00.00.00.-002-A
				Sheet 1 of 1 Sheets

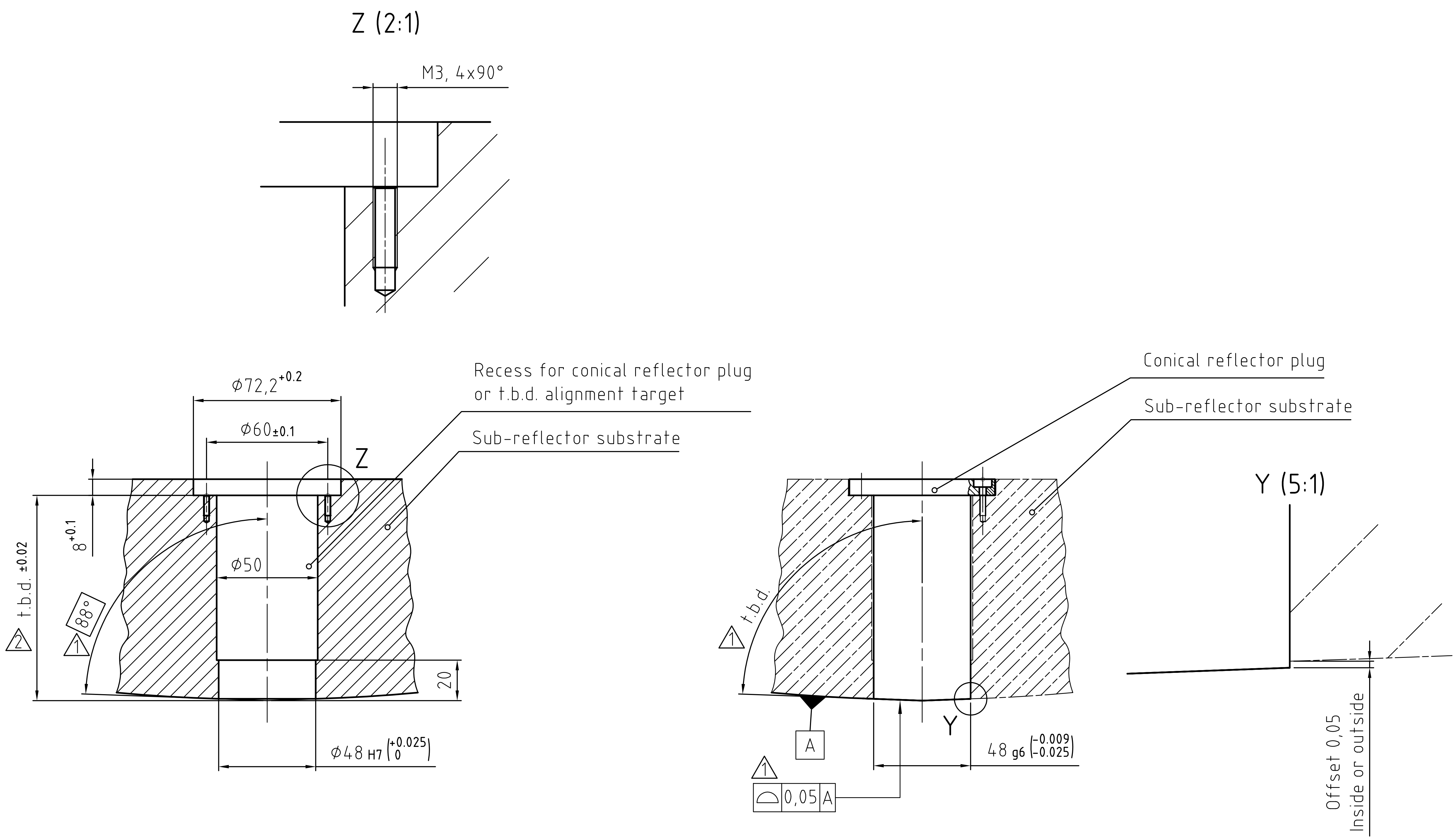


1. Minimum Elevation of the antenna during transport.
2. Minimum distance between antennas for driving between them is 20m.
3. Antennas closer than 20m from the planned transporter route shall be moved to the maximum clearance position, blocked and locked out safely.
4. The axes X_p, Y_p, Z_p are defined in ALMA-20.02.00.00.001-C-DWG

Material:	Tolerances:			ALMA ANTENNA
Surface:	Scale:			
	2003	Date:	Name:	Clearnace profile for passage in central cluster
	Drawn:	11/08/03	QUJ	
	Designed:	11/08/03	MKR	
	Checked:	11/08/03	MKR	
	EUROPEAN SOUTHERN OBSERVATORY Karl-Schwarzschild Str. 2 D-85748 Garching bei München www.eso.org			ANTD-34.00.00.00.-005-A
				Sheet 1 of 1 Sheets



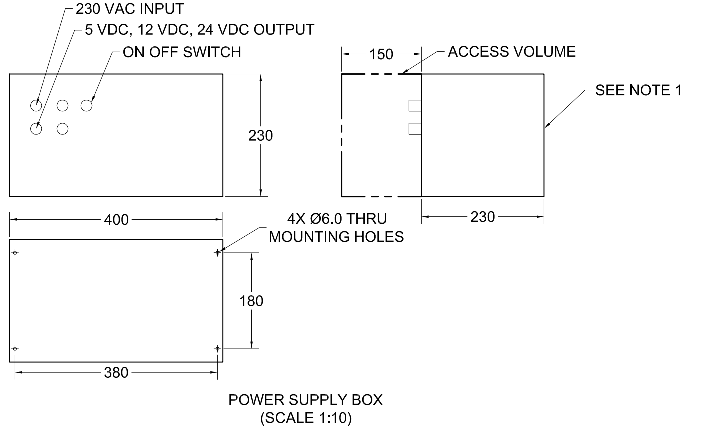
Material:	Tolerances:	ALMA ANTENNA
Surface:	Scale:	
	2003 / Date: / Name: Drawn: 23/10/03 QUJ Designed: 23/10/03 MKR Checked: 23/10/03 SST	Receiver Installation Platform Requirements and Dimensions
	EUROPEAN SOUTHERN OBSERVATORY Karl-Schwarzschild-Str. 2 D-85748 Garching bei München www.eso.org	ANTD-34.00.00.00.-010-A — Sheet 1 of 1 Sheets

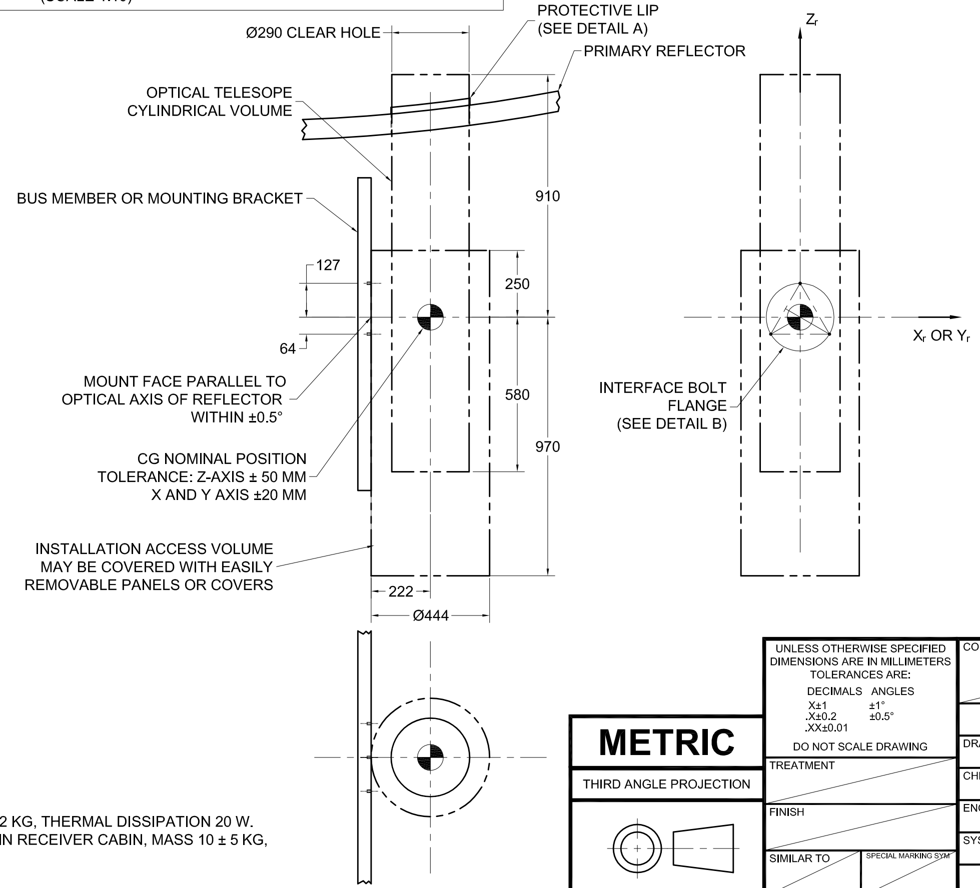


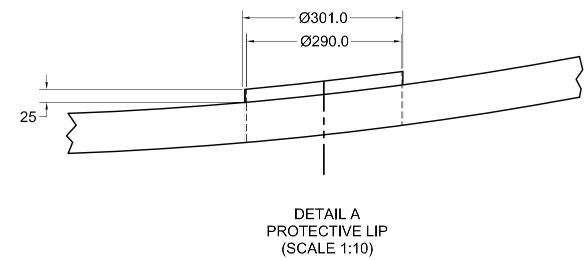
⚠1 Conical surface length to sub-reflector optical surface at Ø48mm

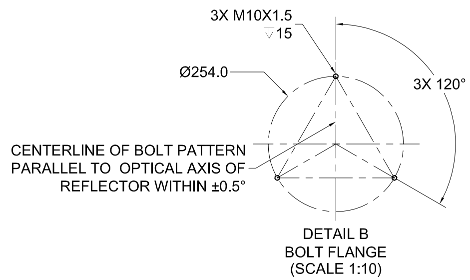
⚠2 Nominal dimension value defined by contractor

Material:	Tolerances:	ALMA-PRODUCTION-ANTENNA
Surface:	Scale: 1:2	
	2003 / Date: / Name: Drawn: 22/10/03 QUJ Designed: 22/10/03 MKR Checked: 22/10/03 SST	Sub-reflector Conical cone
	EUROPEAN SOUTHERN OBSERVATORY Karl-Schwarzschild Str. 2 D-85748 Garching bei München www.eso.org	ANTD-34.00.00.00-008-A-DWG — Sheet 1 of 1 Sheets









NOTES:

1. OPTICAL TELESCOPE MASS 22 ± 2 KG, THERMAL DISSIPATION 20 W.
2. POWER SUPPLY BOX MOUNTED IN RECEIVER CABIN, MASS 10 ± 5 KG, THERMAL DISSIPATION 200 W.

REVISION HISTORY

ZONE	REV	DESCRIPTION	DATE	APPROVED

METRIC

THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS
TOLERANCES ARE:
DECIMALS ANGLES
X±1 ±1°
.X±0.2 ±0.5°
.XX±0.01
DO NOT SCALE DRAWING

TREATMENT
FINISH
SIMILAR TO
SPECIAL MARKING SYM

CONTRACT NO.

APPROVALS		DATE
DRAWN	V.L. GASHO	2003-10-20
CHECKED	S. STANGHELLINI	2003-10-20
ENGR.	V.L. GASHO	2003-10-20
SYSTEMS GROUP		

NATIONAL RADIO ASTRONOMY OBSERVATORY
operated by ASSOCIATED UNIVERSITIES INC. in agreement with THE NATIONAL SCIENCE FOUNDATION

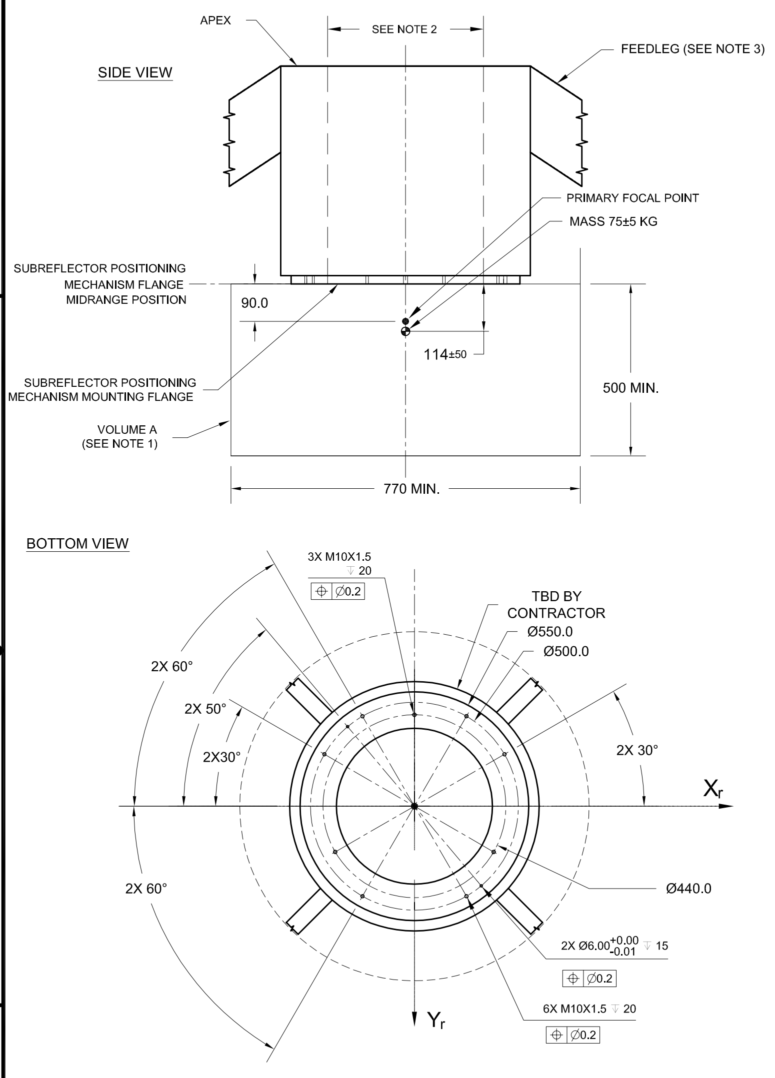
ALMA

TITLE: OPTICAL TELESCOPE FLANGE AND VOLUME

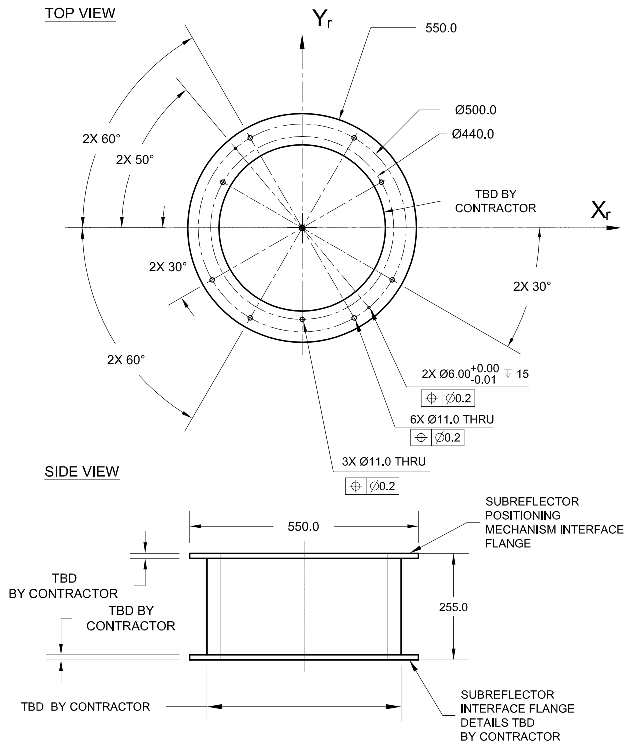
ALMA-TUCSON
949 N. CHERRY AVE.
CAMPUS BLDG. 65
TUCSON, AZ 85721-0655

SIZE	CAGE CODE	DWG NO.	REV.
B		ANTD-34.00.00.00-009-A-DWG	

SCALE 1:20 | CALC. WT | ACT. WT | SHEET 1/1



APEX DETAIL



APEX INTERFACE CYLINDER

NOTES:
1. MATERIAL: ANY MATERIAL WITH DETAILED MATERIAL SPECIFICATIONS TO BE APPROVED.

NOTES:
1. SUBREFLECTOR VOLUME FOR NUTATOR IS Ø840 X 500 AND VOLUME TRAVELS WITH FOCUS STAGE.
2. APEX INTERNAL CLEARANCES SPECIFIED IN HOLOGRAPHY RECEIVER INTERFACE DRAWING ANTD-34.00.00.00-015-A-DWG.
3. ORIENTATION AND SIZING OF FEEDLEG TBD CONTRACTOR

REVISION HISTORY				
ZONE	REV	DESCRIPTION	DATE	APPROVED

METRIC
THIRD ANGLE PROJECTION

ALMA
ATACAMA LARGE MILLIMETER ARRAY

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS
TOLERANCES ARE:
DECIMALS: X±1, .X±0.3, .XX±0.03; ANGLES: ±1°, ±0.5°
DO NOT SCALE DRAWING
TREATMENT
FINISH
SIMILAR TO
SPECIAL MARKING SYM

CONTRACT NO.

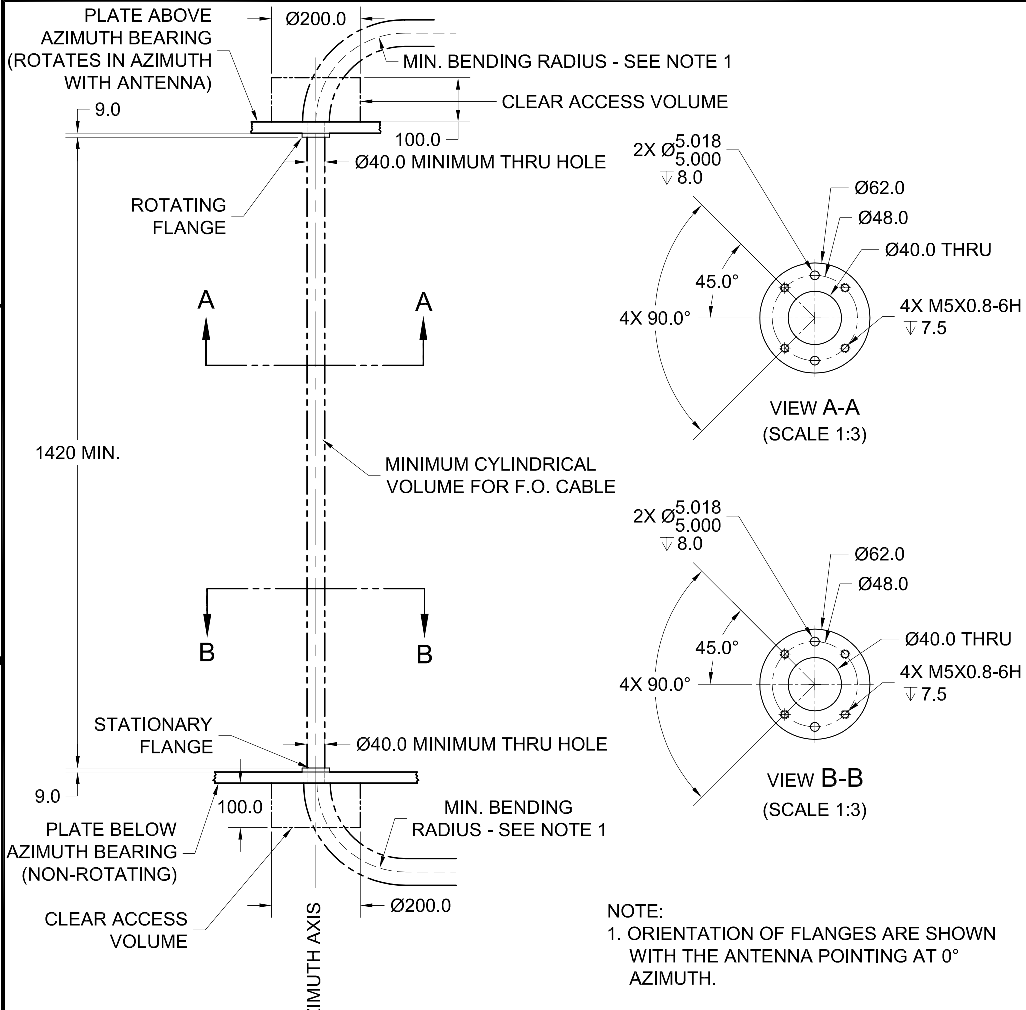
APPROVALS		DATE
DRAWN	V.L. GASHO	2003-09-11
CHECKED	S. STANGHELLINI	2003-09-11
ENGR.	V.L. GASHO	2003-09-11
SYSTEMS GROUP		

NATIONAL RADIO ASTRONOMY OBSERVATORY
operated by ASSOCIATED UNIVERSITIES INC. in agreement with THE NATIONAL SCIENCE FOUNDATION

TITLE: APEX FLANGE AND VOLUME

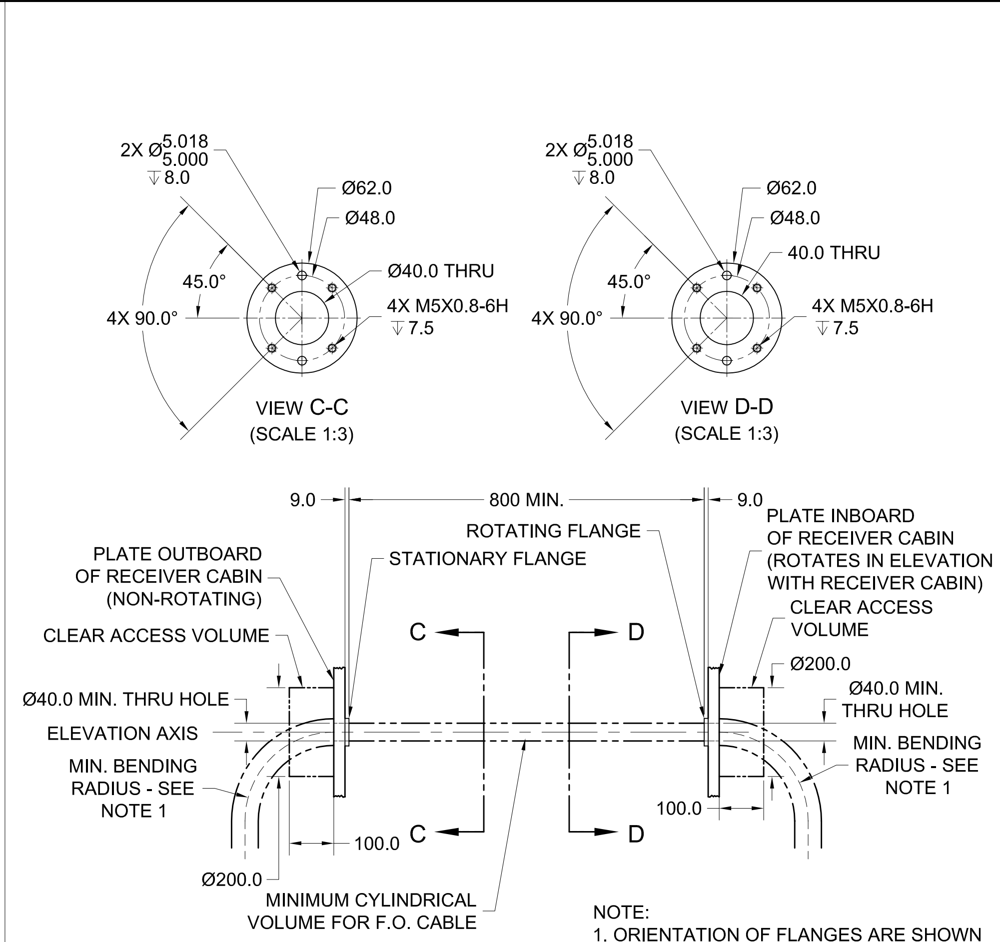
ALMA-TUCSON
949 N. CHERRY AVE.
CAMPUS BLDG. 65
TUCSON, AZ 85721-0655

SIZE: B
CAGE CODE
DWG NO.: ANTD-34.00.00.00-003-A-DWG
REV.: A
SCALE: 1:10
CALC. WT
ACT. WT
SHEET: 1/1



NOTE:
1. ORIENTATION OF FLANGES ARE SHOWN WITH THE ANTENNA POINTING AT 0° AZIMUTH.

AZIMUTH ON-AXIS CABLE WRAP INTERFACE



NOTE:
1. ORIENTATION OF FLANGES ARE SHOWN WITH THE ANTENNA POINTING AT 46° ELEVATION.

ELEVATION ON-AXIS CABLE WRAP INTERFACE

NOTES:
1. MINIMUM BENDING RADIUS OF ON-AXIS FIBER DEFINED IN ALMA-34.00.00.00-50.00.00.00-A-ICD.
2. CLEARANCE DIAMETER OF ON-AXIS FIBER DEFINED IN ALMA-34.00.00.00-50.00.00.00-A-ICD.

METRIC

THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS
TOLERANCES ARE:

DECIMALS	ANGLES
X±1	±1°
.X±0.1	±0.5°
.XX±0.01	

DO NOT SCALE DRAWING

TREATMENT

FINISH

SIMILAR TO — SPECIAL MARKING SYM

CONTRACT NO.

	APPROVALS	DATE
DRAWN	V.L. GASHO	2003-09-12
CHECKED	S. STANGHELLINI	2003-09-12
ENGR.	V.L. GASHO	2003-09-12
SYSTEMS GROUP		

NATIONAL RADIO ASTRONOMY OBSERVATORY
operated by ASSOCIATED UNIVERSITIES INC. in agreement with THE NATIONAL SCIENCE FOUNDATION

ALMA-TUCSON
949 N. CHERRY AVE.
CAMPUS BLDG. 65
TUCSON, AZ 85721-0655

TITLE: ON-AXIS CABLE WRAP INTERFACE

SIZE	CAGE CODE	DWG NO.	REV.
B		ANTD-34.00.00.00-004-A-DWG	

SCALE	CALC. WT	ACT. WT	SHEET
1:12			1/1